

ASTRONOMY

DECEMBER 1977

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NEW FROM



Actual Size 17" x 22"

Jupiter From Io

This dramatic painting reveals an incredible vista that man may never witness first hand: the incredible bulk of Jupiter looming over the surface of its satellite Io. Located deep within Jupiter's intense magnetic field, Io is one of the most lethal places in the entire solar system. To view this scene, we must rely on the imagination of artist John Clark.

To you, our readers, **ASTRONOMY** now offers a series of 8 dynamic, new, full color Art Reprints of some of the best paintings — by artists John Clark, Victor Costanzo, James Hervat, Mark Paternostro, Adolf Schaller and Rick Sternbach — that have appeared in **ASTRONOMY Magazine**.

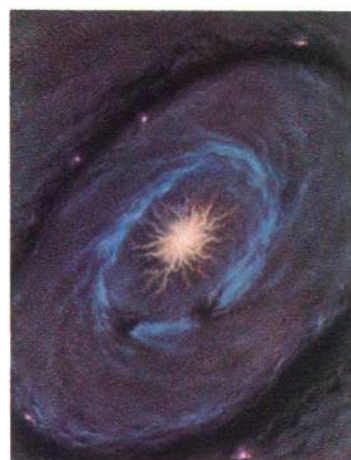
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Black Hole

A nearly invisible small black hole speeds through a dense interstellar cloud of gas and dust, leaving behind a trail of gravitationally disturbed material. The infalling material becomes hot and emits light as it drains out of the known universe. Artist Mark Paternostro speculates on the appearance of these still undetected objects.



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The Galactic Core

The nucleus of our galaxy is one of the true unknowns in our universe. Recent radio and infrared observations suggest that two titanic swirling rings of gas and dust occupy the core of our galaxy. These rings were apparently produced by an explosion 10 million years ago. Victor Costanzo's painting indicates that actual conditions at the galaxy's center remain a mystery.



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Colony in Space

What will space stations and orbiting colonies of the future look like? Artist Rick Sternbach provides an ingenious answer in his painting of a mile wide space station wheeling slowly above the gibbous Earth. Shuttle rockets near the station's hub bring ore from the lunar surface for refinement in the station's zero gravity manufacturing center.

Pluto

The setting sun glints off a low plain of methane ice on the surface of the smallest and most distant planet, Pluto. The cold and forbidding scene — completely alien to Earth dwellers — comes to life in this rendition by James Hervat. The mysteries of Pluto are brought home to us as we stand and gaze back toward our incredibly distant sun.



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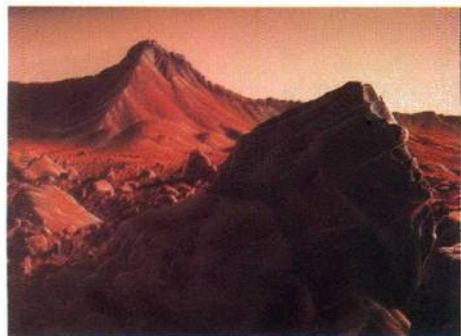
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Saturn

In an unusual perspective from above the north pole of Saturn, we can identify the planet's three main rings and their sizes relative to Saturn itself, enabling us to grasp the vast extent of Saturn's ring system. This remarkable painting by Adolf Schaller gives us a view of the planet not obtainable from Earth.

Vallis Marineris

Photographs returned from Mariner and Viking probes revealed for the first time the immensity of Vallis Marineris, the equatorial canyon of Mars. This painting by Adolf Schaller — meticulously transcribed from overhead Viking photos — takes us to the foot of a blanket of landslide rubble in the canyon itself.



Actual Size: 17" x 22"

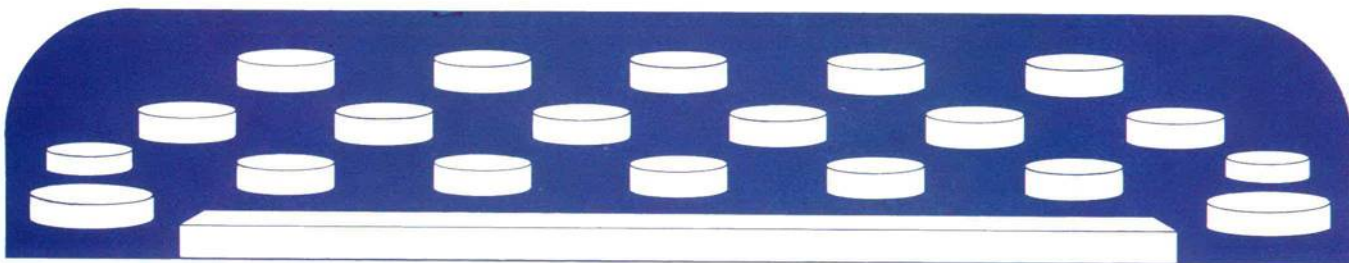


Actual Size: 17" x 22"

Space Telescope

Painted by John Clark from official NASA blueprints, this poster depicts the Space Telescope — a powerful 94 inch (2.4 meter) aperture telescope due to be launched during the early 1980s by NASA's Space Shuttle. This is an accurate depiction of an instrument that will revolutionize man's view of the universe during the decades it remains in operation.

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IN FOCUS

Sirs / My article on stars with companions (September 1977) included mention of an obscure star, CoD 31°622, which was newly reported in 1976 to be a possible close companion of our solar system, perhaps at about 4.4 light-years (the same distance as the Alpha Centauri system). This 1976 estimate was based on its bluish color and its tentative identification as a very faint, close white dwarf. Interest in the star increased as a result of this hypothesis, and the trigonometric parallax, a direct measure of the distance, has now been reported. The distance has been found to be large, probably several hundred light-years. Therefore, the star must be removed from the list of nearby stars. This slightly modifies the statistics of binaries and multiples based on the 36 stars mentioned in the article — but not the basic conclusion that companions are common. As the article noted, probably half or more of all seemingly single stars actually have companions. One-star systems are probably in the minority.

My problem with CoD 31°622 illustrates not only the difficulty of keeping up to date with new astronomical discoveries, but also the danger of trying to be *too* up to date, describing current hypotheses before sufficient data are available. At any given time, our "understanding" is really only the best available information, not necessarily the final answer.

WILLIAM K. HARTMANN
Senior Scientist
Planetary Science Institute

Sir / I'd like to take slight exception to some of the descriptions in the October 1977 Star Dome. Specifically, the description of Stephan's Quintet as "a test for a 16 inch telescope" and "a challenge second to none" seems overly harsh.

My first view of Stephan's Quintet was in late August 1976, with an eight inch f/8 Newtonian. My characteriza-

tion of the two brighter members of the group, NGC-7318 and NGC-7320, was "easy — seen immediately when in field of view", while the other two, NGC-7317 and NGC-7319, I classed as "difficult". Since I was observing in fairly dark skies near Fort Collins, Colo., the limit requirement of "excellent transparency" as given in the article is useful but not necessary.

I have subsequently spotted the group with my 10 inch f/6.5 Newtonian, in quite murky skies near Denver. Under such conditions the two fainter galaxies are exceedingly difficult, but the brighter two are not particularly challenging. (I should add that NGC-7318 is revealed on photographs to be two galaxies in close association, so that while there are five galaxies in the group, four are seen visually.)

Rather than a test for a 16 inch, unless it be in bright skies, I suggest that with superb atmospheric conditions, a five or six inch telescope would reveal the two brighter galaxies. I plan to experiment at first opportunity with diaphragms, to determine the smallest aperture that will show something definite.

RICHARD CLEMENT
Aurora, Colo.

Mr. Clement / Our description of Stephan's Quintet was based on observations made over a period of more than a decade. Perhaps the Colorado skies provide a clearer view than those near Milwaukee or Pittsburgh! Thank you for sharing your thoughts.

A note to other readers: We're always eager to hear from you if you disagree with some of the notes or descriptions in Star Dome. Do you find a galaxy easier to see, or a double more difficult to split? Drop us a line and let us know about it.

Sir / I am a meteorologist with the NBC television affiliate in Louisville. Whenever possible, I try to incorporate

my interest in astronomy into my weathercasts. The Ohio Valley is not known for its interest in astronomy because of the high levels of industrial pollutants and light pollution. I have, however, been very successful in getting people interested in astronomy just by exposing them to it on the air during my show. To the best of my knowledge, I am the only meteorologist (or person, for that matter) who makes astronomy a regular part of a TV news segment. I do hope that ASTRONOMY can encourage other people in the media to cover astronomical events and convey them to their audiences.

NORMAN F. LEWIS
Louisville, Ky.

Sir / In the Washington, D.C. area we have several kinds of pollution, but to the astronomer the worst is undoubtedly sky pollution. We have headlights, store lights, street lights, porch lights, neon lights, and sometimes even searchlights! To go down the street at night with a pair of binoculars is to arouse deep-seated suspicion from the neighbors. However, there is no need to give up your hobby. You can't see it, but you know that right behind that high-rise building is the pristine sparkle of the Pleiades, and in back of that condominium to the west, mighty Arcturus is slowly sinking in a reddish glow. Of course, it's always frustrating to find out that the nova you've discovered to the south is the landing lights of a 747.

But fortunately, there is an alternative. Between gulps of carbon dioxide, in a couple hours with ASTRONOMY, you can travel beyond the path of the outermost sun, farther than any comet has flared or vagrant stardust swirled. Until such time as we can book passage on the Skylab lander, let us enjoy the heavens as we used to know them.

JAMES STEWART
Arlington, Va.

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COVER

Our cover shows M-31, the Andromeda galaxy, visible to the unaided eye as a hazy patch high in the December sky. This magnificent photograph emphasizes the difference between M-31's bright compact nucleus and the wispy delicacy of its spiral structure. Dark lanes of dust and gas filter from the nucleus into the galaxy's spiral arms, and M-31's two small companions, M-32 and NGC-205, complete the picture. This photo is a 30 minute exposure on cooled emulsion High Speed Ektachrome film, obtained with a 12-1/2 inch f/5 Newtonian. This month *ASTRONOMY* examines the formation of ring systems around planets, comparing the process to the birth of the solar system itself. We also look at the various theories propounded to explain the famous "Tunguska blast" of 1908. Photograph by Orien A. Ernest.

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WHY DO PLANETS HAVE RINGS?

by

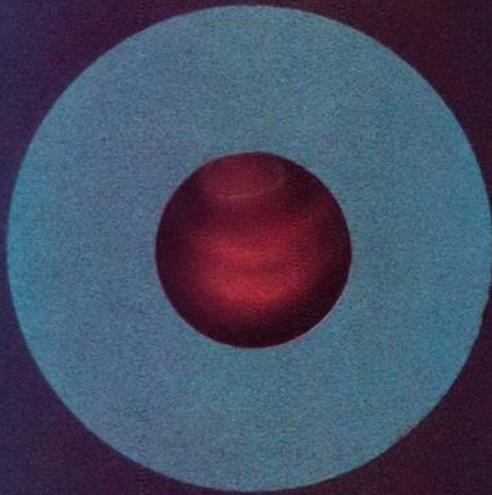
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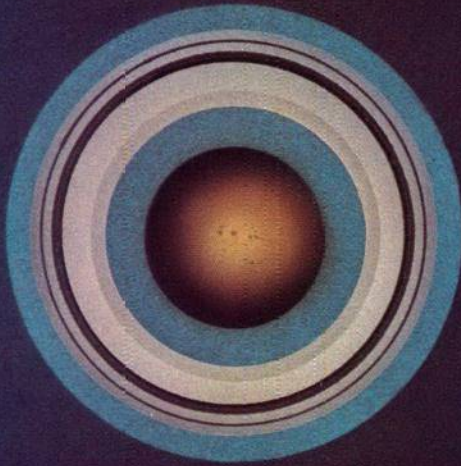
One of the gas giants spins at the outer edge of the solar nebula during an early stage of our solar system's history. Dust and gas spread throughout the system; near the planet, it will begin coalescing into satellites, and perhaps a ring system, as the parent body cools. Planet and satellite formation will end when the T Tauri wind (an energetic stellar wind blasting from the star) sweeps the system clear of the remains of the nebula. Artwork by Mark Paternostro.



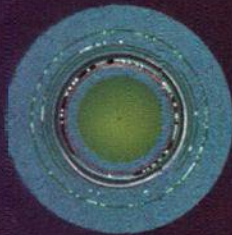
Planets' Roche Limits



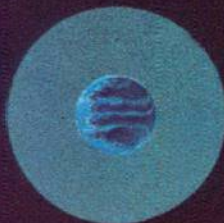
Jupiter's radius — 72,000km
Roche Limit — 175,000km
Closest moon — 180,000km



Saturn's radius — 60,000km
Saturn's rings — 71,000-130,000km
Roche limit — 148,000km
Closest moon — 158,000km



Uranus' radius — 23,000km
Uranus' rings — 44,000-52,000km
Roche limit — 56,000km
Closest moon — 123,000km



Neptune's radius — 22,000km
Roche limit — 54,000km
Closest moon — 353,000km



Earth's radius — 6,400km
Roche limit — 16,000km
Closest moon — 384,000km

Four and a half billion years ago, in a spiral arm near the edge of the Milky Way galaxy, our solar system was born. A disk of dust and gas whirling around a bright, irregularly varying protosun gradually cooled and started to condense, beginning at the outer edge of the nebula and then progressing in toward the central star. Small “snowflakes” of dust and ice formed first, and then larger lumps; snowballs of material collided — sometimes coalescing into larger bodies, sometimes breaking up — until about a dozen Earth sized planets were distributed through the gas surrounding the star. As the cloud cooled still further, ices of methane, ammonia and water formed and condensed onto four of these bodies, which grew large enough to attract the gas surrounding them and to sweep clean the space near their orbits. Gas and dust near these giant planets formed nebular disks, which condensed in turn into moons and rings. Suddenly, planet formation was brought to an end by a blast of wind from the central star that swept the remaining dust and gas from the system, leaving the solar system in the pattern it has today. Near the sun, the temperature never dropped far enough for the lighter elements to condense out, so small terrestrial planets of rock and metal are found here. Farther from the sun are the gas giants with their families of moons, and two with rings.

Why do Saturn and Uranus have rings? Perhaps more important, why don't Jupiter, Neptune or any of the inner planets have any? James B. Pollack, Allen S. Grossman, Ronald Moore and Harold C. Graboske Jr., scientists at NASA's Ames Research Center (Calif.), may have found the answer to this longstanding riddle. Their theory grew out of studies of the early evolution of Jupiter and Saturn. It's a jigsaw puzzle in which a variety of pieces fit neatly together to explain when and why rings can form near planets, and when they cannot.

“If a moon gets too close to its planet, it will be broken up by tidal forces and will form a ring.”

The first question is: Why rings? Why not just a series of moons such as those found farther out from all of the giant planets? The answer is that if a moon gets too close to its planet, it will be broken up by tidal forces and will form a ring; or, conversely, material that is too close to a planet cannot form into a moon in the first place. Why this happens is fairly easy to visualize.

This diagram illustrates the extent of the Roche limits (inside which stable satellites cannot form) of the four largest planets and Earth. Note that the ring systems of Saturn and Uranus consist of particles that orbit the planets entirely within their Roche limits. The relative positions of the closest moon to each planet are also given; Earth's moon orbits its primary much farther out from the Roche limit than the nearest satellites of any of the gas giants. Artwork by Mark Paternostro.

Anyone on a rapidly spinning merry-go-round feels an apparent force toward the outside edge; this is sometimes called centrifugal force and is a very useful tool for understanding what happens. A moon, moving in a great near-circle around its planet, “feels” the same force, which balances the planet's gravitational pull and leaves the moon in a relatively stable orbit. If the moon were a mathematical point of zero diameter, the story would end here. However, moons are extended objects, making the situation more complicated. The orbit of Earth's moon represents a balance between the centrifugal force and Earth's gravity at the center of the moon. The side closest to Earth feels a stronger gravitational attraction, so it is pulled away from the center of the moon, toward Earth. The side farthest away feels less of Earth's gravity and is effectively pulled away from Earth by the centrifugal force. This tug-of-war has permanently distorted the moon into an egg shape with one point always turned toward Earth.

These forces which distort a satellite increase dramatically the closer you get to the planet. If the moon were much closer to Earth, its internal gravity would no longer be able to hold it together. The “back end” would go into an orbit of its own, separate from the middle or the front. The result would be a ring of debris, with each rock in a separate, individually balanced, orbit. The largest pieces left would be those for which the strength of the rock was just able to keep the tidal forces from ripping it apart.

The distance at which moons must break up is called Roche's limit; the table on page 8 shows where Roche's limit is located for each planet in our solar system. The limit is roughly 2-1/2 times the radius of the planet for satellites held together by gravity. Clearly, the rings of both Saturn and Uranus are well within their Roche limits, as the theory predicts, and the moons lie outside, as they must.

What features of solar system and planet formation determine whether or not material will condense into rings near a planet? To answer this question, we must examine current theories of the formation of the solar system and early evolution of the giant planets.

Our understanding of the early solar system comes from two separate areas of astrophysics. One is the analysis of our own solar system as it is today; the other is the study of stars believed to be currently in the process of forming planetary systems. One important group of such stars are called *T Tauri stars* (named after the first one to be discovered).

T Tauri stars are believed to be stars of about the same mass as the sun that have not yet reached the sun's steady nuclear fusion equilibrium — the so-called main sequence. Typically, these stars are 5 to 10 times as bright as they will be when they reach their stable main sequence stage. These stars

are usually found in groups or clusters in or near large clouds of interstellar dust and gas (such as the Orion or Eta Carinae nebulae), believed to be the source of the material of star formation. T Tauri stars are irregular variables; their light output fluctuates by 50 percent or more over a few hours or days. The cause of this variation is not well understood, but it may be related to the flow of gas from the rapidly spinning young star, or to orbiting "protoplanets" occasionally obscuring the star.

Many T Tauri stars also exhibit signs that extra material may be present around the star — a so-called circumstellar envelope, or a "solar nebula" of material for making planets. The oldest of the T Tauri stars show signs of rapid mass loss in the form of a very energetic stellar wind flowing away from the star — the T Tauri wind. This wind certainly precludes the presence of any static solar nebula near the star, and must therefore signal the end of planet and moon formation for that system.

Two major implications for the theory of the early solar system can be gleaned from stellar observation: In addition to suggesting that planet formation ends abruptly, they indicate that it begins gradually. Brand new stars are very bright, producing up to 100 times as much luminous energy as the sun. This energy must heat up the material around the star to the point where only gas can exist in it — no solids or liquids. The gas cannot "stick together" to form planets at the high temperatures (above 3,000 degrees Fahrenheit, or 2,000 degrees Centigrade) which are present in these early stages. Eventually, however, the star settles down to a luminosity more like that of our sun. As the star radiates progressively less energy, the solar nebula cools. When the outermost portions fall below 2,700 degrees Fahrenheit (1,500 degrees Centigrade), dust grains begin to form there. Particles of dust, perhaps looking like small snowflakes, needles or fluffballs, collide and stick together in loose clumps. While this process moves progressively closer to the star, temperatures in the outermost regions continue to drop. Eventually the point is reached where ices — water ice, carbon dioxide (dry) ice, methane and ammonia ices — can also condense out. Now the process of planet formation can proceed rapidly, and as the planets collect the ices to become giant planets, their large gravity also traps some dust and gas in a circumplanetary disk.

The formation of the system of moons around the giant planets is completely analogous to the formation of the solar system, but on a smaller scale. Even the giant planets themselves behaved as small suns, with Jupiter, for example, radiating one percent of the sun's present luminosity for the first 10,000 years of its existence.

This raises another question: Where did the energy come from that the planet radiated in its early stages? For the sun, we know that the source of energy is nuclear fusion — conversion of a small amount of mass to energy. Were the giant planets

also nuclear furnaces in the past? The answer is no. The incredibly high temperatures and pressures required to ignite fusion reactions (making laboratory experiments in fusion nearly impossible) are not attained naturally in any object smaller than 10 times the mass of Jupiter. The source of energy for Jupiter and Saturn is something we all experience every day — gravity. Just as hydroelectric power plants convert gravitational potential energy into the kinetic energy of downward motion and then into electric power, so a collapsing planet or star converts gravitational energy into heat, and heat into the only kind of energy that can escape from the planet: radiation. The giant planets shone by gravitational energy in the past; so do all stars that are still in the process of forming, and so did our sun for the first few million years of its infancy.

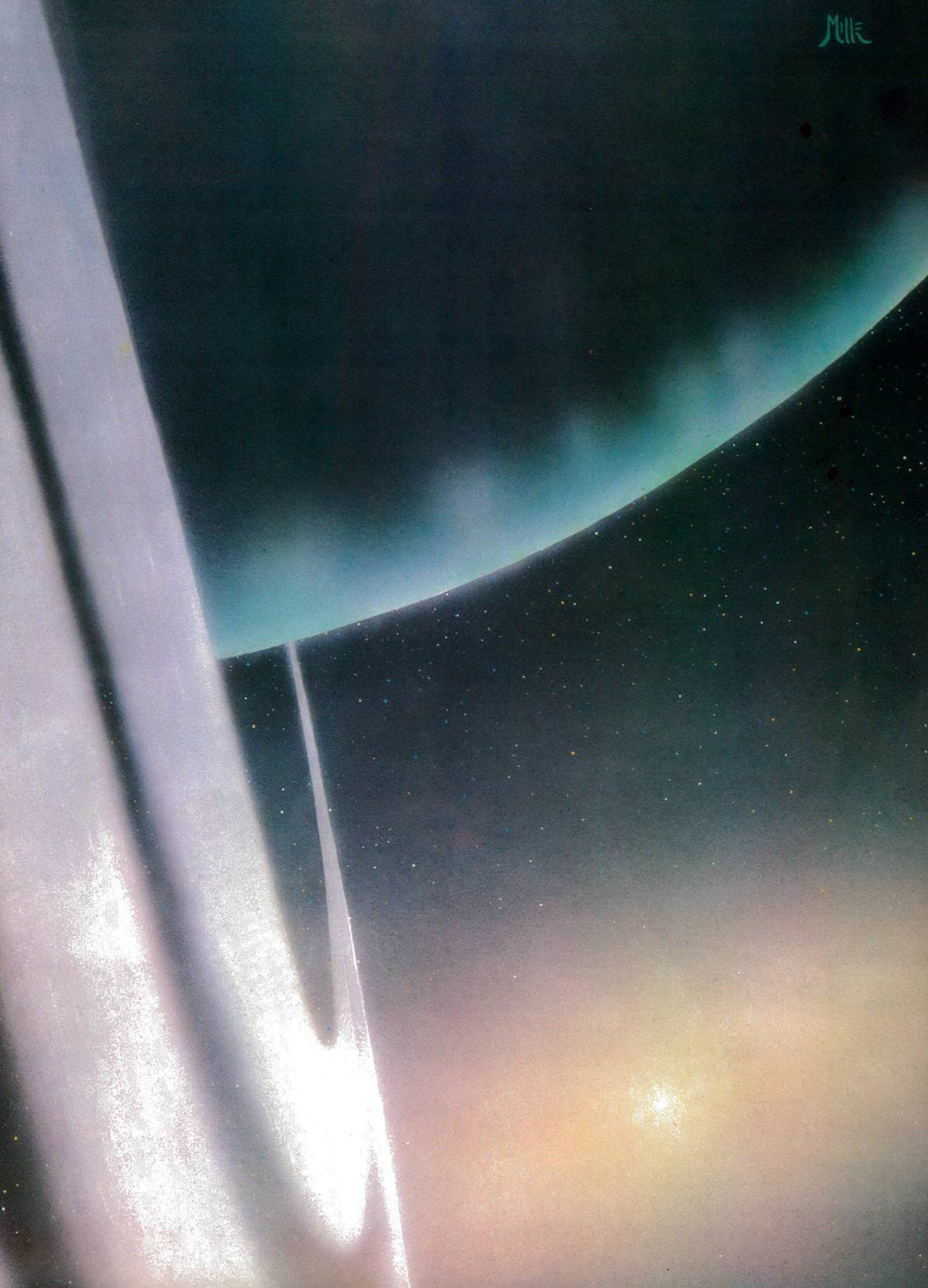
As Jupiter, Saturn, Uranus and Neptune cooled, small moons formed from material that was left over during the formation of the planet, or that was trapped into a circumplanetary shell by the planet's gravitational force. The moons of the giant planets are the fossil record of that process, and can verify our scenario of the early bright phase. The table on page 16 shows the current lineup of satellites for Jupiter and Saturn, with their size, mass, composition and mean density. Just as the planets go from small, rocky terrestrial inner planets to the outer massive gas giants, so there is also a trend in the mean density and mass of the moons.

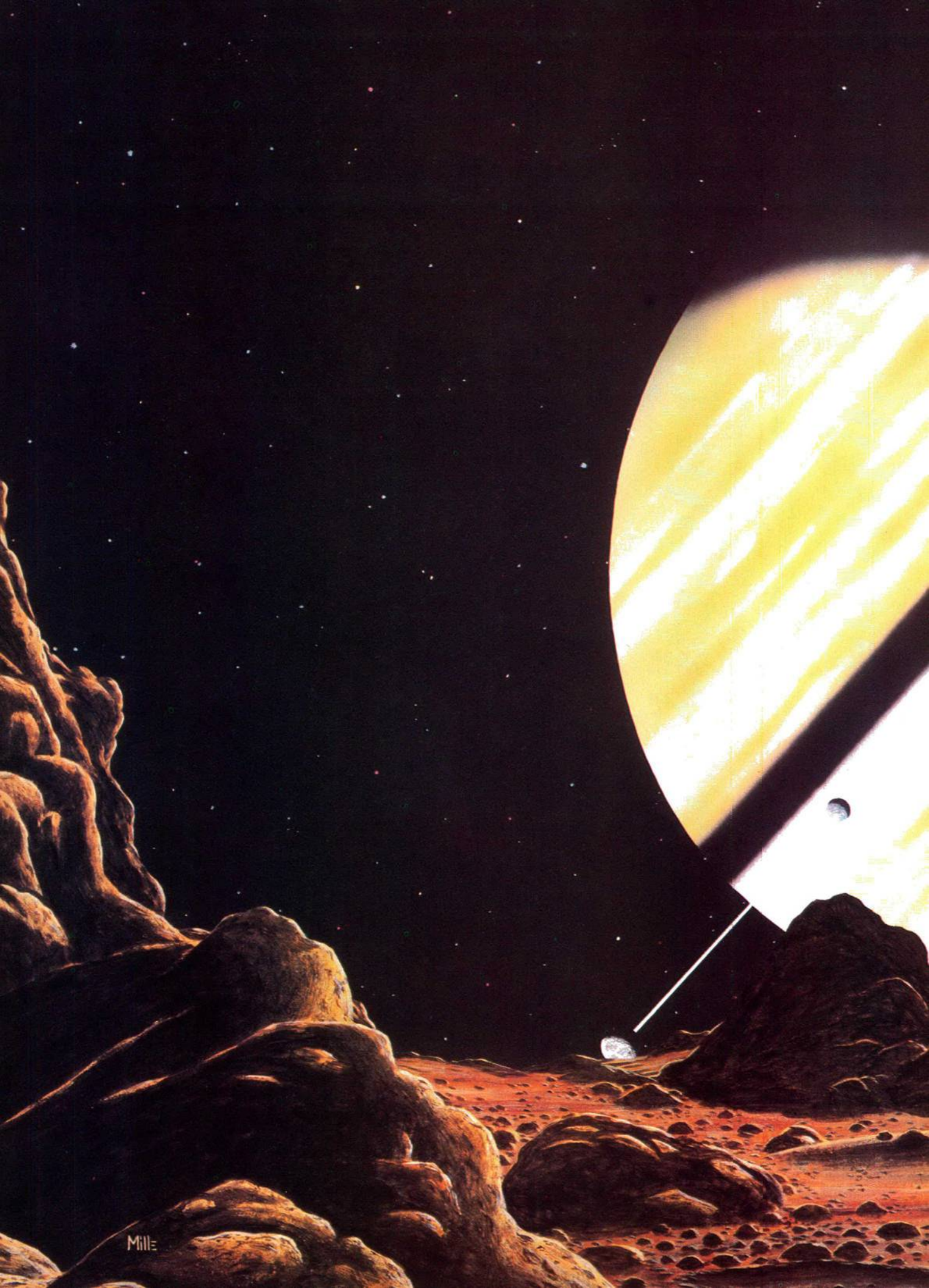
"The giant planets shone by gravitational energy in the past . . . so did our sun for the first few million years of its infancy."

To interpret the mass, density and composition of planets or moons in terms of a model of solar system formation requires an understanding of the chemical composition of the original solar nebula. Observations of clouds of interstellar matter and of other stars besides the sun yield the rather surprising conclusion that nearly everything has essentially the same composition: 73 percent hydrogen, 25 percent helium, and 2 percent everything else. Nuclear reactions inside the sun convert hydrogen to helium, but the new helium is confined to the core of the sun and has left the surface composition unchanged.

Terrestrial planets consist of rock over a nickel-iron core. The elements in rock and the metals are part of that "2 percent everything else". The gas and ices of the outer planets and their moons, on the other hand, contain mostly hydrogen and

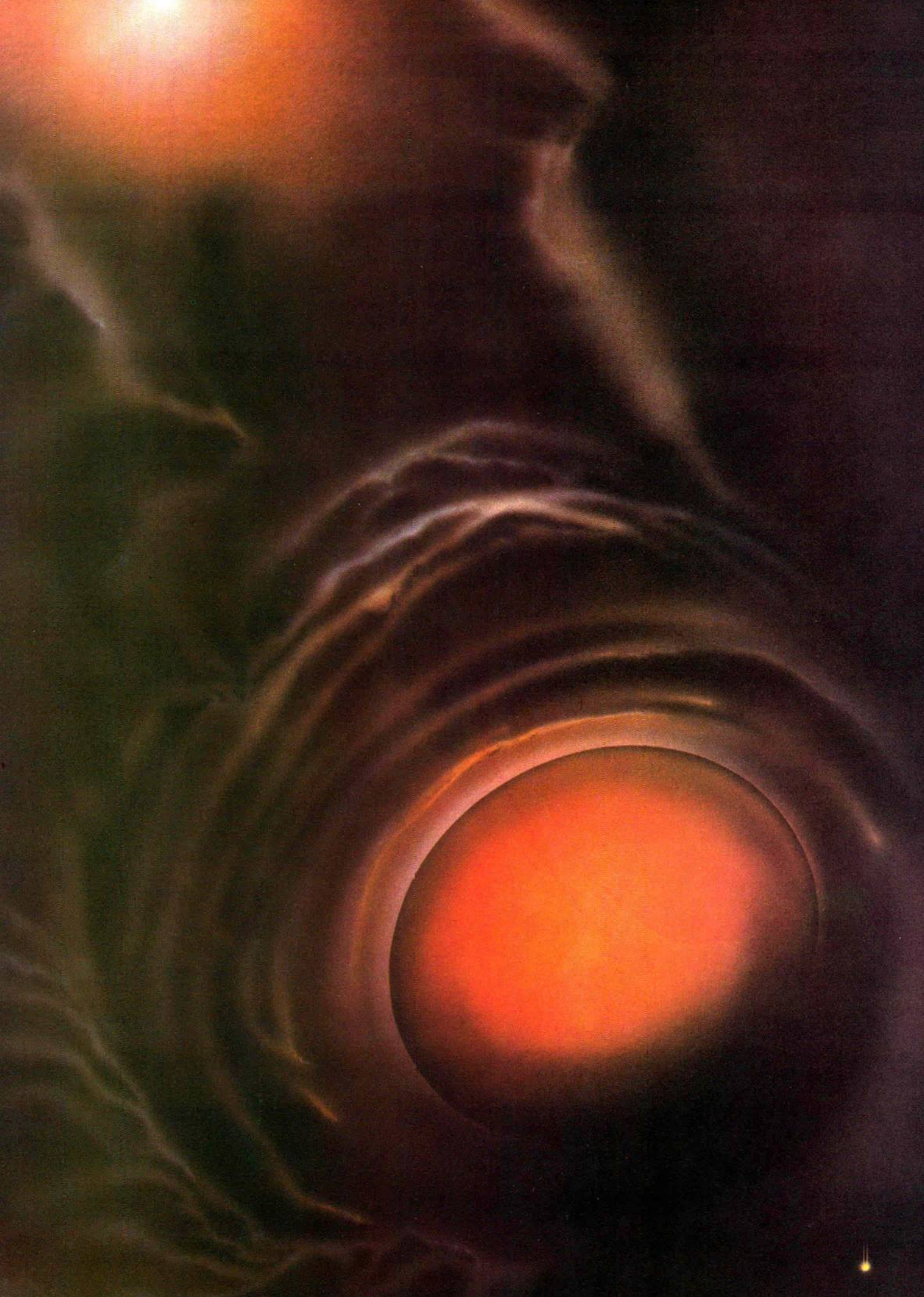
The recently discovered rings of Uranus are neither as wide nor as extensive as those surrounding Saturn. Uranus' rings probably formed much earlier in the planet's history, and much of the material that composed them spiraled into the planet and was consumed in the atmosphere. Here we see the rings from a distance of about 50 miles; Uranus' peculiar axial tilt makes its ring system almost perpendicular to the ecliptic plane. Artwork by Mark Mille.







The rings of Saturn probably formed just before the T Tauri wind, blasting from the sun, cleared the solar system of gas and dust and ended the processes of solar system formation. Thus Saturn's glorious ring system is truly the result of a rare coincidence; other planetary systems are unlikely to contain a planet as spectacular as Saturn! The planet is seen here from one of its inner satellites. Artwork by Mark Mille.



Mass and Mean Density of Planets

Planet	Mass (compared to Earth)	Diameter	Mean Density (relative to water)	Composition
Mercury	0.055	4,900km	5.61	rock
Venus	0.81	12,100km	5.16	rock
Earth	1.0	12,756km	5.5	rock
Mars	0.107	6,800km	4.0	rock
Jupiter	314.5	143,000km	1.3	gas
Saturn	94.1	121,000km	0.7	gas
Uranus	14.4	47,000km	1.36	gas
Neptune	16.7	45,000km	1.30	gas
Pluto	0.1?	2,000km?	?	rock? ice?

some helium. To make a terrestrial planet, therefore, takes 50 to 100 times as much solar nebula material as is left in the final mass of the planet! The Jovian planets have composition more nearly like that of the sun — which means it's more efficient to make a Jupiter or Saturn than to make an Earth or Mars; essentially all the material of the solar nebula in the planet's neighborhood can be used.

The mean density of planets or satellites depends both on their composition and their mass. Thus, among Saturn's satellites, although Titan probably contains more of the lighter ices (methane and ammonia) than Rhea and Tethys, it is denser than those two because it is more than 100 times as massive, giving it much stronger gravity with which to compress its material. By comparing the density of moons of similar masses, we get a clue to their composition — from dense, rocky moons to low density satellites of ice.

"We can predict from this theory [that] Neptune may have a ring system similar to that of Uranus."

The satellites of Saturn have progressively larger mass farther from the planet — up to enormous Titan. This supports the idea that the planet cooled gradually, allowing first water ice and then methane and ammonia ices to collect on the outer satellites. In the region of the rings, water ice was able to condense, but not methane or ammonia; at Titan, most of the material was able to condense to make that large moon. Beyond Titan there was less material present initially to form moons, so the outer moons are less massive — just as Saturn, Uranus and Neptune are less massive than Jupiter.

The observed progression of the mass and composition of the moons and planets is confirmation of

two parts of our theory — the existence of an early, high luminosity phase for the giant planets, and the formation of the moons as minor "planetary" systems.

The material near the giant planets could not condense into rings until the planets had cooled enough and reached roughly their present size. Thus, Jupiter's lack of rings is simple to explain. If planet and satellite formation stopped abruptly 4.5 billion years ago, Jupiter was still too hot and bright to allow ices to condense inside its Roche limit. Just as the inner planets have no large ice and gas component, so Jupiter's inner moons are mainly rock, and there are no icy rings around the planet.

But Uranus and Neptune are smaller than Jupiter and Saturn, as well as farther from the sun, so they must have had plenty of time to cool. If rings invariably form as soon as the region close to the planets is cool enough, why don't Uranus and Neptune have rings — or do they?

The mathematical theory on which this article is based was developed a few months before the discovery of Uranus' rings last March — awkward timing not atypical of scientific endeavor — and therefore the "why not?" is argued this way:

Once rings consisting of small chunks of ice have formed, if there is still gas left (as there must be without "outside interference"), these pieces will experience drag forces — air resistance — as they move through the gases. The drag forces will tend to make the lumps of ice spiral down into the planet, just as satellites orbiting in Earth's upper atmosphere eventually spiral in to a meteoric end. For the outer planets, the rings must have formed earlier than Saturn's rings and been largely — or perhaps entirely — destroyed before the outpouring T Tauri wind blew away from the remaining dust and gas and froze the system in its present state.

Why didn't the satellites also spiral in? Drag force depends on the size and mass of the object involved, and its speed through the gas. For example, the size of hailstones that can be formed in a thunder cloud depends on the speed of the winds that keep them from falling. Vertical winds pro-

Stable satellites cannot form inside a planet's Roche limit, but will break up into tiny fragments and begin falling into the planet. Material that began coalescing very close to a planet (as shown here) had no chance of ever forming into moons — but may have ended up as a ring system if conditions were right. Artwork by Mark Paternostro.

MEAN DENSITY OF SATELLITES

Satellites of Jupiter

Satellite	Mass (compared to Earth)	Diameter	Mean Density (relative to water)	Composition
Io	.013	3,240km	4.3	rock
Europa	.008	2,830km	4.0	rock
Ganymede	.025	4,900km	2.4	mostly rock, some ice
Callisto	.016	4,570km	1.9	rock and ice

Satellites of Saturn

Satellite	Mass (compared to Earth)	Diameter	Mean Density (relative to water)	Composition
Mimas	.000006	* 500km	0.6	rock and water ices
Enceladus	.00001	* 500km	0.9	rock and water ices
Tethys	.0001	* 1,000km	1.1	rock and water ices
Dione	.0002	* 1,000km	2.3	rock and water ices
Rhea	.0003	1,350km	1.4	mixed ices
Titan	.02	4,950km	1.9	mixed ices
Hyperion	.00002	* 400km	3.6	ice and rock
Iapetus	.0004	* 1,200km	2.7	ice and rock
Phoebe	.000005	* 300km	2.1	ice and rock

* Size estimated from brightness

Information listed only for those satellites with measured mass

duce upward drag forces to counter gravity. To form the very rare tennis ball sized hailstones, speeds of 250 to 300 m.p.h. are required. In ordinary clouds, lower speeds can only support smaller hailstones — fortunately!

In the nebular region surrounding the giant planets, outside the Roche limits, the moons formed very rapidly, becoming large enough to be only slightly affected by gas resistance before the drag forces could cause them to spiral in. Inside the Roche limit, tidal forces prevented the objects from becoming large. Thus drag was important for the ring particles, but not for the moons.

How can this theory account for the discovery of rings around Uranus? A brief description of Saturn's and Uranus' rings gives a clue. The rings around Saturn are wide, with narrow "empty" spaces between — Cassini's divisions. These rings consist of medium to large chunks of dirty water ice, according to radar studies of the way they reflect radiation. Uranus' rings, on the other hand, are narrow, with extremely broad "Cassini divisions", and quite likely are composed mainly of very small particles. Perhaps Uranus formed an impressive system of rings, lost them because of the "drag" forces, and continued to produce small particles inside the Roche limit until the time of the T Tauri wind. If this is true, it implies that Neptune should also have rings: If rings formed continually around Uranus, they should have done the same near Neptune. It will probably require observations from space to check this suggestion, however, since

Neptune is 50 percent farther from us than Uranus, and Uranus' rings are difficult enough to detect!

Our explanation for Saturn's glorious ring system is just the "cosmic coincidence" of Saturn cooling enough to allow rings to form just barely in time before the T Tauri wind ended the processes of solar system formation. Too soon, and Saturn would have had only modest rings, like Uranus; too late, and it would have had no rings, like Jupiter. We can predict two things from this theory: Neptune may have a ring system similar to that of Uranus, and that other planetary systems are unlikely to have as spectacular a ringed planet as our Saturn.

Can any other predictions be made from our theory? We can "predict" that when mathematical models are built for Uranus and Neptune, they will show that these planets also have had a high luminosity phase, but one which was considerably shorter than Saturn's or Jupiter's. We can also predict a very abrupt turn-on of the T Tauri wind in those stars currently forming planets. Thus stellar astronomers or space probes may provide the next piece of evidence in the chain of deduction as we ask each of the planets, "What were you doing in 4.5 billion B.C.?"

Lee Anne Willson has been for the last four years an Associate Professor of Physics at Iowa State University in Ames, Iowa, and has also worked in the astronomy department at the University of Washington in Seattle. Her main field of study is variable stars (including T Tauri stars) — their spectra, atmospheres, and physical characteristics.

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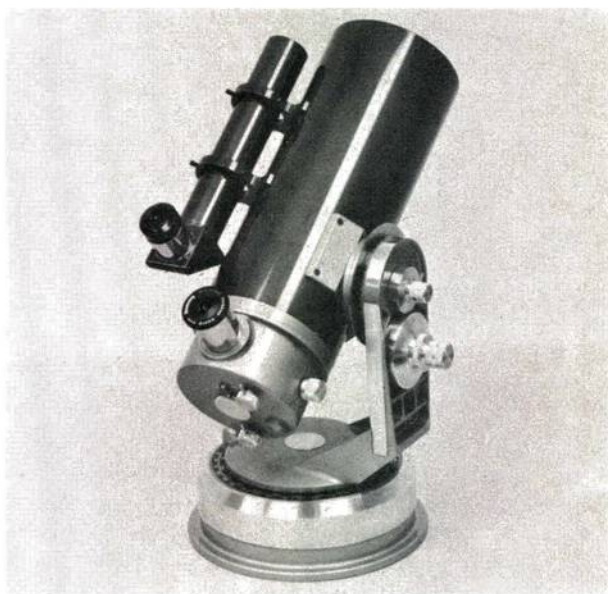
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TUNGUSKA: COLLISION WITH A COMET

by
James E. Oberg

The tremendous explosion that flattened hundreds of square miles of Siberian pine forest in 1908 was probably equal in power to that of a modern thermonuclear detonation (its atmospheric pressure wave actually did circle the planet twice). It's still sending shock waves around the world; scientific repercussions of the event (known as the "Tunguska Blast") have yet to be stilled.

As eyewitness reports trickled in from the remote region where the blast occurred, specialists assumed it was a large meteor impact. Studies were interrupted by World War I, the Bolshevik Revolution and the subsequent Russian civil war, so that the first scientific expedition didn't reach the scene of the explosion until 20 years after the event. The scientists had extracted financing from the young regime in Moscow with tantalizing hints that vast hunks of metal might have fallen from the sky, ready for smelting and industrial applications.

The results of those early expeditions haunted specialists for many years. No crater was ever found, despite the fact that trees were radially smashed down for miles in all directions. Years later, samples collected by an earlier expedition were found to contain microscopic metallic spherules of meteoric material. But other features of the detonation continued to puzzle investigators.

Almost 40 years after the blast, one specialist noted a strange similarity between the discoveries at the Tunguska site and reports of conditions at Hiroshima and Nagasaki, the targets of atomic bombs at the end of World War II. Suggestions were made that the otherwise enigmatic Tunguska blast had actually been an atomic explosion that had been set off either naturally, by some secret Earth culture, or by an alien vehicle from another world. Considering all the evidence, even the atom bomb theory was not too wild to be true. Other scientists conjured up visions of antimatter, miniblack holes, freak fiery whirlwinds, and other hypothetical effects. But none was able to satisfactorily explain all of the Tunguska evidence.

The generally accepted hypothesis among "traditionalist" schools of geology and space physics is that the Tunguska blast was caused by the impact of a cometary nucleus with Earth. The explosion was caused when the tremendous kinetic energy of the onrushing space object was converted into heat by its passage through the atmosphere.

Whatever the explanation, however, this nearly 70-year-old explosion forms a first rate scientific puzzle. It was clearly unexplainable in

terms of 1908 science or 1928 science, and may still be so even with 1977 science. It is a genuine anomaly, and therefore is a possible source of new understandings of natural events in the universe — events which do not follow the accepted "laws" of nature as scientists propose them.

Any force that causes explosions like the Tunguska blast, perhaps measuring the equivalent of 10 to 15 million tons of TNT (in military parlance, 10 to 15 megatons), obviously must be understood for one important reason: It could happen again. If it was a natural event, when and where could it strike again in a world now heavily populated and prone to localized war scares? What would happen today if such an explosion occurred, not in the depths of Siberia, but over one of the world's large cities?

Any theory describing the cause of the Tunguska blast must account for a number of important factors. Most students of the event accept the following:

- 1) The force of the explosion was equal to that of a modern thermonuclear bomb.
- 2) The explosion occurred at an altitude of several miles above the ground.
- 3) The explosion resulted in a special combination of thermal pulse, light flash, shock wave and magnetic flux.
- 4) The blasted region of the forest had an irregular shape, in a pattern vaguely similar to the outline of a butterfly.
- 5) Eyewitnesses referred to a glowing fireball. Many of the eyewitness accounts are contradictory unless we assume a change in course of the object.
- 6) For several days after the event (and before news of it had reached the rest of the world), the skies over Europe were brightly lit throughout the night.
- 7) Natives of the region have a highly developed folklore of the event, including tales of (and explanations for) strange sicknesses among their reindeer.
- 8) Decades later, specialists noticed an accelerated growth of trees in the region immediately surrounding the blast.

What might the famous Tunguska blast of 1908 have looked like to an eyewitness? The accounts we have are somewhat contradictory, but most refer to a glowing fireball. When we consider that the explosion had the force of a modern thermonuclear bomb, we can conjure up an awesome spectacle, perhaps not unlike that portrayed here. Artwork by Mark Paternostro.







Most of the evidence gathered by scientists indicates that the cause of the Tunguska explosion was the collision of Earth with the nucleus of a comet as portrayed here. Other theories to account for the blast are numerous; one hypothesizes the explosion of a nuclear powered alien spaceship. But only the comet theory satisfactorily explains most of the facts known today — including the presence at the Tunguska site of large amounts of carbonaceous chondritic material, of which comet nuclei are likely to be composed. Artwork by Mark Paternostre.

The Tunguska Mystery - Solved?

by

Ian Ridpath

Two new studies have apparently confirmed that in 1908 Earth had its first observed collision with a comet. The comet hit Earth in the valley of the Stony Tunguska river, 500 miles northwest of Lake Baikal in Siberia, and exploded with a force equivalent to a 12-1/2 megaton bomb.

As explained in the main article, scientists were baffled because expeditions to the site could find no sign of a crater, although trees had been flattened for up to 20 miles around by the blast. Siberian eye-witnesses said the object appeared like a blue-white fireball, brighter than the sun, as it descended to Earth. Some reports even told of strange radioactivity at the site, and in the atmosphere after the blast.

One controversial theory for the Tunguska event was that it was caused by the crash of a nuclear powered spaceship which burned up in the atmosphere. This idea has recently sparked several sensational books.

However, results just announced from the latest Soviet expedition have provided vital clues to the Tunguska object's true identity.

Microscopic particles found in the soil by investigators from the Soviet Academy of Sciences consist of a crumbly type of rock from space known as a carbonaceous chondrite. Thousands of tons of this material are believed to be scattered around the area of the fall. Cosmic dust of similar composition has been collected from the upper atmosphere by rockets.

Soviet astronomers have concluded that the Tunguska body was a normal lump of rock from space, probably the head of a comet, which is believed to have had a carbonaceous chondrite composition. This confirms a previous suggestion about the nature of the Tunguska body (see *Astro-News*, May 1977).

This same conclusion was reached independently by astronomer John Brown of Glasgow University and

physicist David Hughes of Sheffield University in England. They noted in an article in *Nature* that the comet, which was about 40 yards in diameter, was far too small to have been seen before it hit Earth, particularly since it was arriving at high speed from the same direction as the sun.

Brown and Hughes showed that any associated radioactivity that might have occurred would have been produced in the hot gas as the comet burned up in the atmosphere, creating temperatures of millions of degrees and literally turning the air blue before it shattered explosively at a height of five or six miles.

The fragments found by the Soviet scientists are all that is left of the first comet observed to have hit Earth. But similar objects are expected to hit Earth every 2,000 years or so, according to Brown and Hughes.

We might not be so lucky about where the next one impacts!

9) There have been conflicting reports of traces of radioactivity, both at the site and elsewhere around the world, in the tree growth rings of 1909 (the year following the blast).

Thomas Atkins and John Baxter claimed in their book *The Fire Came By* (Doubleday, 1976) that the "spaceship hypothesis" was the only possible explanation for all these facts. Some type of interstellar vehicle was attempting to make a landing on Earth and was steering for an uninhabited region when its nuclear power plant detonated (presumably by accident). The hull of the ship acted like a Claymore mine, shaping the charge into the irregular pattern. Radioactive clouds drifted over Europe, were absorbed in trees both at the scene and around the world, and contributed to radiation sickness among the natives. As at Hiroshima and Nagasaki, the results of atomic reactions in the trees accelerated their growth tremendously.

Refuting the theory that a comet could have caused such an event, proponents of the spaceship hypothesis ask for any other similar events which can be traced to comets. They ask why the comet was not seen in the skies prior to the impact. They ask how a "normal" physical/chemical blast could have produced results which today are associated only with nuclear detonations, such as magnetic pulses, glowing clouds and accelerated growth. Lastly, they ask how a comet could have accounted for the enhanced radioactivity of the region.

In response, proponents of the comet hypothesis point out much recent evidence which has been overlooked or ignored by advocates of the spaceship

theory. According to several prominent astronomers, the evidence today is stronger than ever that the Tunguska blast was an entirely natural event caused by collision of a comet with Earth. Frightening as it may seem, these scientists suggest that a similar blast might happen again, anywhere on Earth, at any time. It is important to determine if they're correct!

Recent studies in the field of meteoritics have cast a great deal of light on the types of things that fall from the sky. While astronomers once classified meteorites (which a meteor in the sky becomes when it reaches the ground) as stony or stony-iron, a new type of meteorite called *carbonaceous chondrite* has recently been described. Not many specimens have been recovered in the past, since the material is ordinarily very fragile (it has been likened in structural strength to frozen cotton candy) and usually burns up completely, leaving only a thin dust to sift down to the ground. The fragments that do reach the ground usually disintegrate because of the weather, or if noticed are usually not recognized since they look just like ordinary terrestrial objects.

A good place to search for all types of meteorites would be on a giant clean sheet of ice or sand. Meteorite hunters often travel to the dry salt lakes of the western United States where, standing at measured locations, they scan the flat lake bed with binoculars. But the most exciting results have recently come from Antarctica, where the slow flow of glaciers have been depositing collections of meteorites into certain traps where the ice evapo-

rates, leaving a carpet of sky stones. Most of the stones in this truly representative sample are carbonaceous chondrite meteorites. Only 10 percent or less of the meteorites are the "classical" stony or stony-iron type.

Similar results have come from studies of sky photographs taken by the Smithsonian Observatory's Prairie Network of automatic cameras. What the scientists discovered, via triangulation of the meteor trails from two or more widely spaced photographs, was that the brightest and most explosive meteors almost always disintegrated totally in flight. Furthermore, their orbits were those characteristic of comets, not of the stony and stony-iron meteorites (whose orbits prior to impacting with Earth were characteristic of wandering asteroids).

The connection with the Tunguska event comes in when the pre-impact trajectory of the Tunguska object is calculated. When we take into account the haziness and distortion that had grown into most of the accounts during the years between experience and description, a reasonably consistent ballistic trajectory can be reconstructed. It places the object on nearly a collision course from high above the ecliptic plane — just like a comet. More importantly, it also places the path of the object as coming out of the sunward side of Earth — that is, on a path which would be concealed from the view of people on Earth because of daytime solar glare. The reason for the object's invisibility from Earth prior to impact becomes clear.

The Tunguska object thus seems to have had a path through space similar in direction to that of other ordinary objects that burn and flare up in the atmosphere, only to disintegrate to dust which, without special measures, becomes indistinguishable from ordinary terrestrial dirt. But do such objects explode? And could they have exploded as powerfully as did the Tunguska object?

Here, too, recent studies have provided crucial missing information. In 1965, a tremendous midair explosion was recorded near Revelstoke, an industrial town in western Canada. Barographic records indicate that the blast was in the tens of kilotons range — about that of the atomic bombs that flattened Hiroshima and Nagasaki. This blast, however, was several dozen miles from any city and was at an extremely high altitude, so little ground damage was recorded.

The only effect that searchers could find the next day at what must have been ground zero for the blast was a faint layer of soot over the newly fallen snow. Suspecting that it was not simply industrial contamination, scientists collected samples of the dirty powder and analyzed it in their laboratories. The result: carbonaceous chondrite powder!

The Revelstoke explosion was not unique. Sensitive microbarographs built to monitor the atmosphere for illegal nuclear bomb tests have been recording randomly spaced high altitude explosions

all over the world — some of considerable size. Many similar reports exist in Fortean literature, including explosions followed by the fall of black dust or black rain. (Charles Fort was a collector of "inexplicable" natural events; here, again, Fort seems to have collected data that scientists may take a century to appreciate.)

With these results on record, several specialists suggested that the Tunguska blast was merely a larger carbonaceous chondrite object, probably from the nucleus of a "burnt-out" comet. Alternately, the comet *might* have had a tail thousands or tens of thousands of miles long, but it would not have been visible from Earth as it was in the daytime sky. These specialists suggest, however, that the tail of the "Tunguska Comet" *was* seen from Earth after the blast, and that it formed the "glowing cloud" over Europe.

Any investigator can satisfy himself that Europe was indeed "down-sun" of the Tunguska impact, which is exactly where you would expect the comet's tail to have entered the upper atmosphere. (Similar reports were not recorded in regions east of Tunguska, where normal atmospheric winds would have carried dust thrown up by the explosion itself.) But why should such a dust cloud glow in the dark, as this remarkable cloud did?

Again, certain relevant facts are not recognized by proponents of the spaceship hypothesis. The explosion took place on the morning of June 30 — nearly midsummer. In northern Europe at this time of year, the famous "white nights" phenomenon occurs. Because of the high latitude of much of Europe (much farther north than the U.S.), the sun is only 15 degrees below the northern horizon at midnight. (That's equivalent to only one hour's rotation on the equator, or twilight about one hour after sunset.)

The high dust clouds were being illuminated by the midnight sun, as astronomers in Europe realized almost at once. At several locations, spectrograms were taken of the light, revealing it to be identical to sunlight and not at all like the weird glows imagined for radioactive fumes or magnetic disturbances. What puzzled the scientists for years was the cause of the high altitude dust, since they likened it to the effects produced by the explosion of the Krakatoa volcano a few decades before. Since the cloud was deposited directly into the upper atmosphere over Europe, it dissipated much more rapidly than the clouds transported by wind from the 1883 Indonesian eruption. But atmospheric turbidity (haziness) induced by Tunguska cometary dust was measurable weeks later at an observatory in California, confirming the dust hypothesis.

Comparing the kinetic energy blast of a comet nucleus with a similar sized thermonuclear explosion, specialists have calculated that a nuclear thermal pulse would have lasted for more than 30 seconds. Yet the heat wave from the Tunguska explosion, according to eyewitnesses, was very brief

— more typical of a kinetic explosion. Similarly, even high powered chemical explosions cause magnetic pulses, mushroom clouds, and other effects once thought to have been the exclusive domain of thermonuclear detonations.

But what about the radioactivity? Although a radioactive comet is not beyond the realm of possibility, comet proponents cast doubt upon the actual existence of any abnormal radioactivity at all. Several Soviet expeditions deliberately sought traces but found none, while one specialist, Aleksey Zolotov, who did report positive results in 1960, later withdrew his claims when the radioisotopes were traced to fallout from nearby Soviet nuclear tests. But Zolotov has once again claimed to have found new traces of radiation from the scene of the blast. Other specialists, recalling Zolotov's earlier unfounded claims, do not consider either his methods or results trustworthy.

In the U.S., nuclear chemist Willard Libby made an independent search for radioisotope carbon-14 in 1965. Libby, who won a Nobel Prize for development of the carbon-14 dating method, was attempting to determine if the blast could have been caused by any type of thermonuclear reaction (he was mainly concerned with testing the antimatter theory). According to published accounts in **The Fire Came By** and elsewhere, Libby did indeed find abnormally high levels of fallout in tree rings grown the year after the blast. Unfortunately, this is not what Libby said at all.

Following publication of the claim that Libby's work "proved" that a nuclear explosion had occurred, the retired scientist told *ASTRONOMY* contributing editor James Oberg what his results had really shown: Any increase in radioactivity in 1909, compared with other years, was probably only a random fluctuation, comparable in size to other up and down fluctuations in subsequent years. Libby's colleagues had computed the amount of carbon-14 that would have been created by any type of thermonuclear reaction (including a hydrogen bomb), and the detected amounts were at most 1/7 as large as would have been required. Libby affirmed that his experiment had positively excluded the possibility of a 10 or larger megaton blast having occurred anywhere in the northern hemisphere anytime in 1908.

If radiation did not cause the accelerated growth of trees around the blast site, what had? Spaceship theorists had long debunked the suggestion that the forest fire ignited by the thermal pulse of the blast had induced the growth by clearing the undergrowth and fertilizing the soil. Yet a Soviet forestry ministry survey team, sent to investigate the growth mechanism in the hope of being able to induce it in logging areas elsewhere, discovered that the accelerated growth did indeed follow the outlines of the burned areas quite well — despite the fact that some unburnt areas were quite close to ground zero (they did not experience accelerated

growth), and some burnt areas were quite distant (conversely, they did show signs of a faster growth rate following the event).

Dynamics specialists in Moscow attempted to recreate the shock waves of the original event, assuming that the passage of the object through the air produced a supersonic shock wave, and that at the end of this trail a detonation wave resulted from the sudden disintegration of the comet. The specialists strung explosives along a string suspended above a "forest" of miniature match sticks. When the explosives were set off, the match sticks were smashed down in a beautiful butterfly pattern, quite similar to the results mapped by the expeditions to the Tunguska site. The combination of sonic boom and detonation were quite sufficient to account for the seemingly odd shape of the flattened area.

Soviet ethnographers have examined stories of the natives and are unable to separate fact from fiction in these colorful tales of the descent of a god from heaven and his destruction of native storehouses and herds. No trace of the reindeer sickness can be found, nor have any descendants of the natives shown any sign of the radiation-induced diseases and mutations made familiar to modern science by the Hiroshima and Nagasaki explosions. While effects on these two Japanese cities will continue for several generations in a measurable degree, no similar effects have ever been found in the region of the Tunguska blast.

Has science really solved the Tunguska mystery? For the first time since the forest was flattened and the night sky over Europe glowed with the red of a northern dawn, there appear to be no "loose ends" in the dominant scientific theory of the event. A new understanding of meteorics, of the composition and orbits of a hitherto unsuspected class of meteorites, and of the possible composition of related comets, have all resulted — at least partially — from astronomers' bafflement at the anomalies, contradictions and mysteries of the Tunguska blast.

As for the spaceship hypothesis, it too has made a contribution to science. From the earliest days when men looked at the sky with curiosity, beholding its amazing and often frightening phenomena, some theorists have always explained everything by saying that the gods caused it, or the man in the moon caused it, or (in terms of today's mythology) extraterrestrial visitors caused it. As a scientific theory, such suggestions are currently both irrefutable and dead-ended, and lead only to blind faith and frustrated curiosity. The methodology of science has a different goal: to understand the mechanisms, predict similar events, and someday to be able to prevent such repetitions. Considering the consequences of a Tunguska blast occurring somewhere else on Earth today, we hope that science is on the right track! The full story of the Tunguska comet mystery suggests that it is. 

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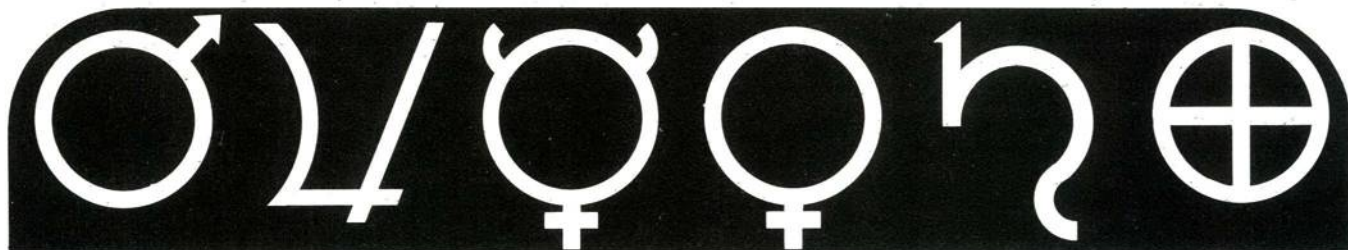
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SKY ALMANAC

JUPITER AT OPPOSITION

December Satellites of Jupiter
12:00 p.m. EST, 9:00 p.m. PST

1	41032	• ••••	16	40123	• ••••
2	40123	• ••••	17	42103	• ••••
3	42013	• ••••	18	4203	• ••••
4	41023	• ••••	19	43012	• ••••
5	43012	• ••••	20	43120	• ••••
6	31240	• ••••	21	43201	• ••••
7	32014	• ••••	22	4102	• ••••
8	10324	• ••••	23	04123	• ••••
9	01234	• ••••	24	21043	• ••••
10	2034	• ••••	25	2034	• ••••
11	12034	• ••••	26	3024	• ••••
12	30124	• ••••	27	3104	• ••••
13	31204	• ••••	28	32014	• ••••
14	32041	• ••••	29	13024	• ••••
15	1402	• ••••	30	01234	• ••••
			31	2103	• ••••

Planets begin returning to the evening sky this month as Jupiter, Mars and Saturn slowly move into their best positions for observing. We'll therefore have a choice of three brilliant "Christmas stars" for the yearend holiday season.

Jupiter

The giant planet reaches opposition — the position in its orbit at which it is on the other side of Earth from the sun — on Dec. 22, when it will be located near the western border of Gemini, little more than one degree south of the rich open cluster M-35. Jupiter's opposition date would be a good time to photograph the conjunction of these two objects. You might also try to obtain a photo sequence of Jupiter moving past the cluster from about a week before to a week after opposition.

Jupiter's apparent diameter will be at its maximum for this year at opposition, when its equatorial diameter will be 47.44 seconds of arc. Its polar diameter (slightly lower because of the planet's oblateness) will be 44.28 seconds of arc. Jupiter's distance from Earth at opposition will be 386 million miles (620 million kilometers).

The Lagoon nebula (M-8) is centered in this photograph of the Sagittarius region of the summer Milky Way. In addition to the starclouds that dominate the area, also visible are the Trifid nebula (M-20), just north of the Lagoon, several other Messier objects, and huge lanes of dark dust and gas that block the light of the stars behind them. A 10 inch focus f/5.6 lens was used to obtain this 30 minute exposure on 2-1/2 x 3-1/4 inch cooled emulsion High Speed Ektachrome film. Photograph by Orien A. Ernest.

The four major satellites of Jupiter orbit the planet in periods ranging from less than two days to 17 days. You can see them change position from one night to the next; their motions are often evident after only a few hours' observation. You only need a small telescope to detect all four, and you can frequently make out several in rigidly held (or tripod mounted) binoculars. This table shows the approximate positions of the moons at about 12 p.m. EST on the mornings indicated. The first column on the left shows the date; the second column identifies the moons by their positions relative to Jupiter's disk (1 = Io, 2 = Europa, 3 = Ganymede, 4 = Callisto, 0 = Jupiter's disk). The third column gives the satellites' positions as they appear through a telescope. The orientation of the satellite is given with south up as seen through a standard inverting telescope.



Planet Finder

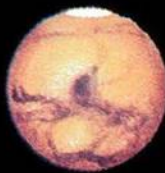


(A) Mercury

Dec. 1
R.A. 18h03m
Dec. -25°45'
Mag. -0.2

(B) Mercury

Dec. 15
R.A. 18h26m
Dec. -22°57'
Mag. +1.3



(M) Mars

Dec. 1 15
R.A. 8h56m 8h59m
Dec. +19°59' +20°23'
Mag. -0.1 -0.4



(C) Ceres

Dec. 1 15
R.A. 16h10m 16h34m
Dec. -18°36' -19°56'
Mag. +9.0 +9.0



(N) Neptune

Dec. 15
R.A. 17h00m
Dec. -21°18'
Mag. +7.7



SUN

The sun is within the stippled zone throughout the month. Planets and stars near this area are not easily seen.



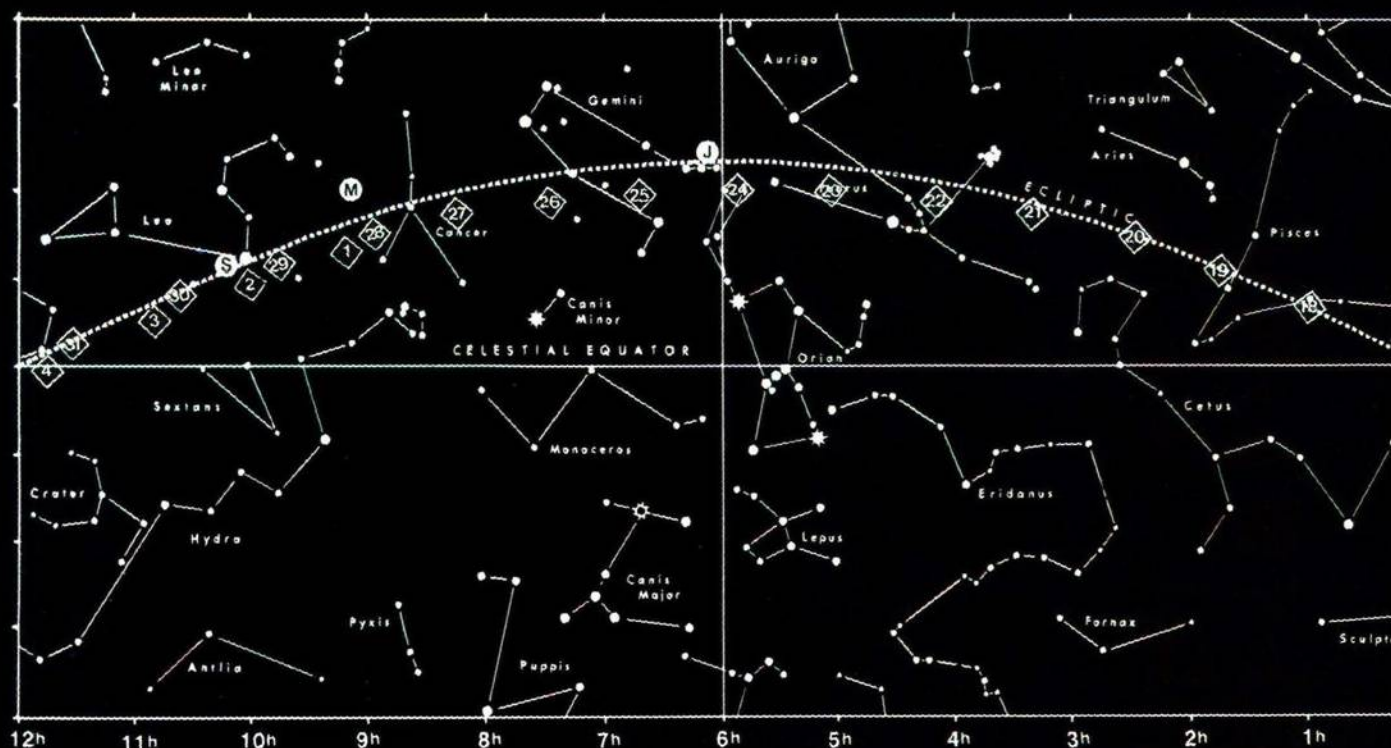
(S) Saturn

Dec. 1 15
R.A. 10h12m 10h12m
Dec. +12°31' +12°33'
Mag. +0.7 +0.7



(U) Uranus

Dec. 15
R.A. 14h48m
Dec. -15°50'
Mag. +5.7



The chart shows the positions of the moon, planets and brightest asteroids for the current month. Letters within the circles correspond to the letters beside each object in the data section above the map. Additional information about each object is given there. R.A. = right ascension and Dec. = declination, the two coordinates used to locate astronomical objects. The general coordinate system is indicated around the edge of the map. Mag. = magnitude, a

December 1977



(V) Vesta

Dec.	1	15
R.A.	14h02m	14h28m
Dec.	-6°37'	-8°42'
Mag.	+8.3	+8.1



(J) Jupiter

Dec.	1	15
R.A.	6h16m	6h08m
Dec.	+23°05'	+23°09'
Mag.	-2.3	-2.3



(Y) Venus

Dec.	1	
R.A.	15h41m	
Dec.	-18°43'	
Mag.	-3.4	

(Z) Venus

Dec.	15	
R.A.	16h55m	
Dec.	-22°15'	
Mag.	-3.4	



(P) Pluto

Dec.	15
R.A.	13h24m
Dec.	+9°17'
Mag.	+14



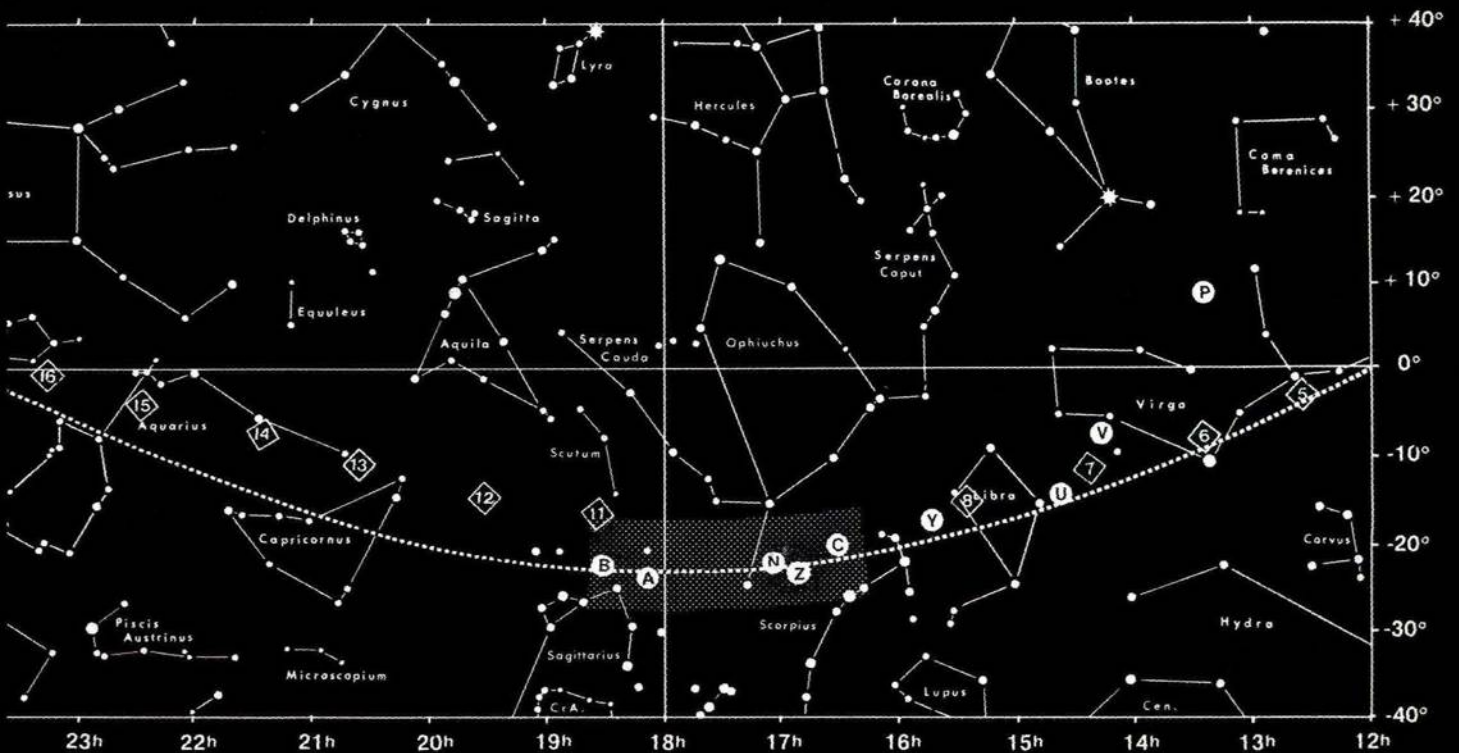
First Quarter
December 17



Full Moon
December 25



Last Quarter
December 3



measurement of the object's brightness. (The minus magnitudes indicate very bright planets.) The diamonds with numbers within them indicate the position of the moon for each day of the month; the numbers correspond to the dates. Positions of the planets are for the 15th of the month except for Mercury and Venus which are shown on both the 1st and 15th. Certain areas of this map and the Star Dome chart overlap each month.



All month, Jupiter far outshines everything else in the evening sky at magnitude -2.3. Being opposite the sun in the sky, it rises at sunset and sets at dawn, so you can see Jupiter at any hour of the night; persons who work early shifts will have just as much chance to take a look at Jupiter as those who go to bed early.

On Christmas morning, Jupiter will be about five degrees north of the full moon (a position it will also be in on Jan. 21, 1978).

Mars

Mars is brightening rapidly as it approaches opposition, which it will reach on Jan. 22. During December, its magnitude shoots up from -0.1 to -0.8. Mars' brightness always increases very rapidly near opposition — and declines rapidly afterward.

This is not one of Mars' most favorable oppositions. Mars has an eccentric orbit so that the differences between its *perihelion* (point nearest the sun) and *aphelion* (farthest from the sun) distances are proportionately greater than those of the other planets. When Mars reaches opposition and perihelion simultaneously, it becomes extremely bright and a fine sight through the telescope. But when opposition coincides with aphelion, Mars is much more distant from Earth and therefore much dimmer. Mars' opposition in January will occur when the planet is quite near aphelion, so Mars will neither be as large nor as bright as it has been other years.

Mars' apparent diameter grows from 10.81 to 13.52 seconds of arc dur-

Satellite Shadows on Jupiter			
Date	Satellite	Transit Begins (EST)	Transit Ends (EST)
Dec. 1	1	5:42 a.m.	7:54 a.m.
3	1	12:10 a.m.	2:23 a.m.
3	2	2:15 a.m.	4:56 a.m.
4	1	6:39 p.m.	9:51 p.m.
5	3	1:30 a.m.	4:25 a.m.
10	1	2:04 a.m.	4:17 a.m.
11	1	8:32 p.m.	10:45 p.m.
12	3	5:29 a.m.	8:25 a.m.
13	2	6:11 p.m.	8:52 p.m.
17	1	3:58 a.m.	6:11 a.m.
18-19	1	10:26 p.m.	12:39 a.m.
20	2	8:48 p.m.	11:29 p.m.
24	1	5:52 a.m.	8:05 a.m.
26	1	12:21 a.m.	2:23 a.m.
27	1	6:49 p.m.	9:02 p.m.
27-28	2	11:09 p.m.	2:06 a.m.
1 = Io		3 = Ganymede	
2 = Europa		4 = Callisto	

ing December as its distance from Earth decreases from 80 million miles (129 million kilometers) to 64 million miles (103 million kilometers). On Dec. 13, Mars is stationary and begins *retrograde* motion — that is, it appears to move from east to west against the background of the stars, rather than vice versa.

Mars will be located seven degrees north of the waning gibbous moon on Dec. 1, and eight degrees north of the waning gibbous moon on the 28th. During the month, the red planet is in the constellation Cancer; it rises about 9 p.m. and is visible the rest of the night.

Saturn

Saturn is located in Leo, not far from first magnitude Regulus. Saturn itself, shining at magnitude +0.7, is brighter than the star, so you shouldn't worry about confusing the two. It pops over the horizon about 10 p.m. and is easily visible in the eastern sky until sunrise.

Saturn is stationary and begins retrograde motion only one day before Mars — on Dec. 12. As it approaches opposition (which it will reach on Feb. 16), its apparent diameter increases from 17.8 to 18.9 seconds of arc. Note that this is the diameter of the disk alone; the rings make Saturn appear much larger, for they extend across 44 seconds of arc by month's end — almost as large as the disk of Jupiter. Saturn's distance from Earth decreases during December from 838 million miles (1,347 million kilometers) to 796 million miles (1,280 million kilometers).

Saturn will be five degrees north of the waning gibbous moon on the 2nd and again on the 30th. On Jan. 20,

Saturn will be located little more than one degree north of Regulus.

Mercury, Venus

Both inner planets will be visible at the beginning of December, but too close to the sun to be seen by month's end. On the 3rd, Mercury will be at greatest eastern elongation and visible very low over the southwestern horizon just after sunset. It will soon drop into the twilight, being at inferior conjunction by Dec. 21.

Venus, the brightest planet, is still available for viewing in the eastern sky before sunrise, but is now very near the sun and hard to see. By the end of the month, it should be lost in the sun's glow. It will reach superior conjunction on Jan. 22, after which Venus will reappear in the evening sky.

Meteors

The Geminid meteor shower — after the Perseids the year's best — will be at their peak on the night of Dec. 13-14. The moon, only three days past new and setting early in the evening, will not interfere with observation. The Geminids are slow moving meteors, and at their best, you can expect to see about 50 per hour. Their *radiant* (the point from which the meteors appear to be coming) is located near the bright star Castor.

Winter Solstice

In its annual apparent path around the sky, the sun reaches its farthest point south of the celestial equator on Dec. 21 at 6:24 p.m. EST. Winter will officially begin in the northern hemisphere, and summer in the southern. ☞

Top right: On Aug. 16, the five-percent-lit crescent moon occulted Mercury for observers in the eastern United States. The photo, taken just before occultation, shows Mercury about to disappear behind the moon's dark limb. This is a one second exposure on Kodachrome 400, obtained at the prime focus of a six inch Criterion at f/8. Photograph by Robert Berry. **Top left:** Jupiter and Mars were separated by only 1/2 degree on Sept. 4. This photo, a 15 second exposure on Kodachrome II, shows both planets, as well as Jupiter's four bright moons and background stars. A fine home built Newtonian at f/5 was used. Photograph by Rudy Kokich and Mike Vranjican. **Center:** This photo shows the naked eye view of Jupiter and Mars on the night of their close conjunction in the constellation Gemini. This is a one minute guided exposure on Ektachrome 200, taken with a 50mm lens at f/2. Photograph by Fred Espenak. **Bottom:** On Aug. 12, Mars was in the constellation Taurus; this photo shows its location that night near the Pleiades and Hyades clusters. A 55mm lens at f/1.7 was used for this three minute guided exposure on Ektachrome 200 pushed to ASA 400. Photograph by James R. Westlake Jr.



ASTRONOMY REVIEWS

The Study of Comets

edited by BERTRAM DONN

1,083 pages, hardcover, \$11.25*
U.S. Government Printing Office

Comets remain among the most spectacular but least understood members of the solar system, even in the age of planetary landings and extrasolar probes. But recent advances in chemistry, instrumentation technology, and astronautics have contributed greatly to our understanding of the nature and origin of these sporadic celestial spectacles.

The latest theories and findings about comets have been compiled by NASA's Goddard Space Flight Center (near Washington, D.C.) into this massive and overwhelming two volume set. The basis for the compilation was a scientific conference held in the wake of the Kohoutek project in 1973-74.

Unlike many highly technical but disjointed "conference proceedings", this production is complete, readable and well organized. More than half is devoted to summaries and speculations about various features of comets and comet watching. Specific results from Kohoutek, Bennett, and other recent comets fill much of the remaining half. Sizable sections also examine cometary chemistry, plasma physics, and the development of space probes to comets.

Among the most puzzling characteristics of comets are their orbital paths: eccentric and at every imaginable inclination to the ecliptic. The evolution of comet orbits is the topic of several papers that begin with basics and progress to advanced statistics and differential equations. Enigmas include some claims that observable long-period comets cannot evolve into observable short-period comets (so where do they come from?), and that long-period comets could not have formed within the planetary regions of the solar system. This is

not reconcilable with other claims that Uranus and Neptune are conglomerations of ancient comet material, while modern comets are leftover debris.

In the last three centuries, no hyperbolic (solar escape) comet orbits have ever been detected. But some elliptical orbits are so nearly parabolic that planetary perturbations can throw the comets free of the solar system into interstellar space. Other comets become meteor showers and (presumably) zodiacal dust. High powered computers and mathematics have offered new insights into these old problems.

With few exceptions, the easy reading of most of these papers is a pleasant surprise (the truly basic concept of the Oort cloud is used freely by a dozen authors before it is "accidentally" defined on page 663). The phrase "as is well known" is used only once, justifiably. Occasional repetition of background material by different authors is actually useful with this kind of approach.

All comets do not follow precise ballistic trajectories, to the bewilderment and embarrassment of past astronomers. Solar heating causes outgassing from some comets, resulting in a jet action that depends on comet composition, rotational rate and spin axis. Extensive discussions of this topic are in the form of astronomers' sharing of their own experiences and insights; such discussion transcripts (which follow most papers at length) add tremendously to readers' appreciation of the topic and of the processes of modern astronomical research.

Anyone who has ever prowled around an old observatory will enjoy the discussion of comet data collections (photographs, logbooks and other records dating back a century or more) that fill every available nook and cranny. Although much is being lost, miscatalogued or destroyed,

several astronomers vouched for such a collection's usefulness in the light of recent discoveries: "We have been able to utilize observations to infer solar wind and comet properties, so far, back to 1889," says one. Another proposed a government grant for an unemployed astronomer to microfilm all the old records throughout the country (a committee was set up to study the proposal).

Conferees were frustrated that they could not answer a simple question: "What is a normal comet?" Scientists such as Whipple, Marsden, Delsemme, O'Dell, Maran and Kohoutek discussed cometary attributes and were forced to agree with another colleague's closing remarks: "Each comet is an individual. Comets have steadfastly resisted recent attempts at classification."

Already, space probes such as Mariner 4 and HEOS 2 have detected dust particles ejected by passing comets. A long section of the book deals with a space probe sent directly into a comet. "Only space missions to comets can give us the 'quantum jump' in knowledge necessary to solve the most fundamental problems of comets," writes Whipple. Actual mission plans and instrumentation are given for proposed probes to comets Encke, Giacobini-Zinner, and Halley between 1980 and 1985.

These missions may very well take place, since the fundamental problems of comets are intimately tied up with the origins of the entire solar system. For anyone who wants to make a "quantum jump" in their own understanding of comets, this imposing-looking two volume set is a surprisingly easy and inexpensive path. *James E. Oberg.*

*Published by NASA (1976).
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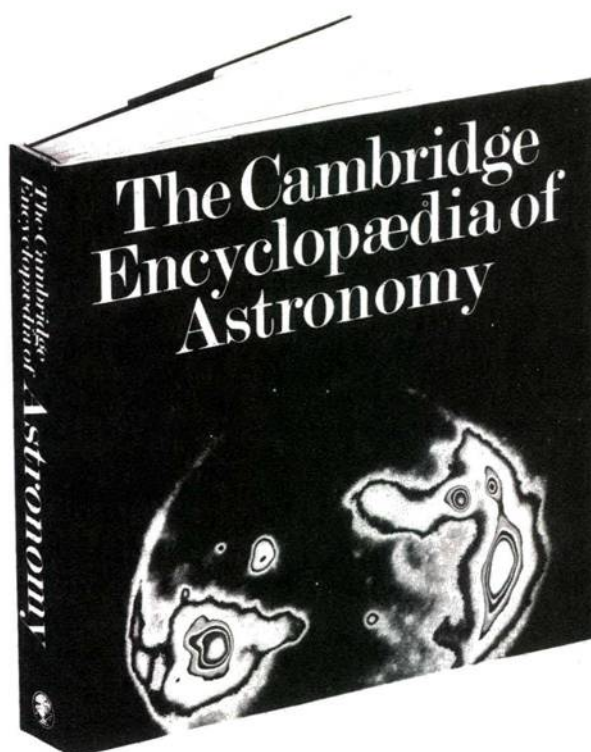
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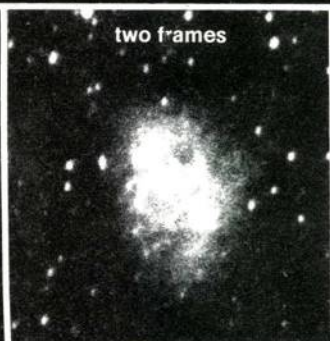
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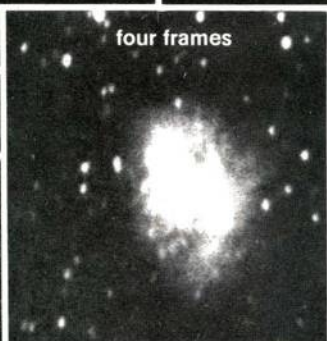
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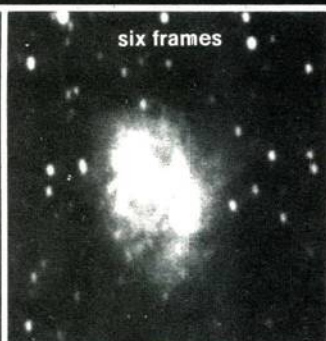
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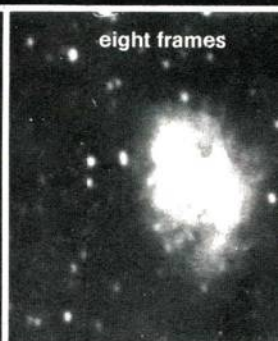
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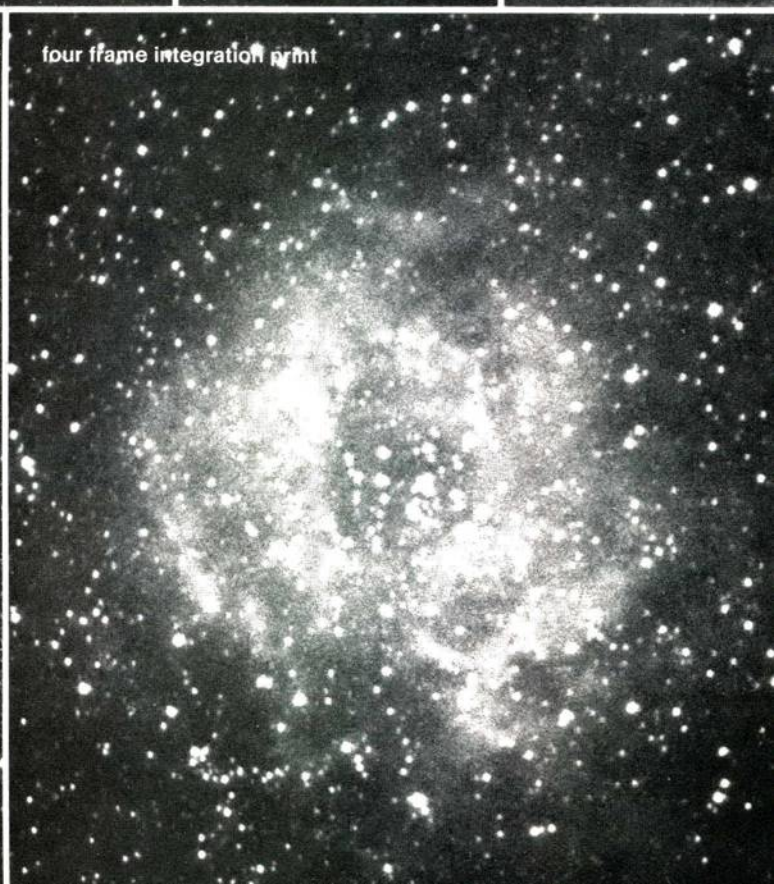
six frames



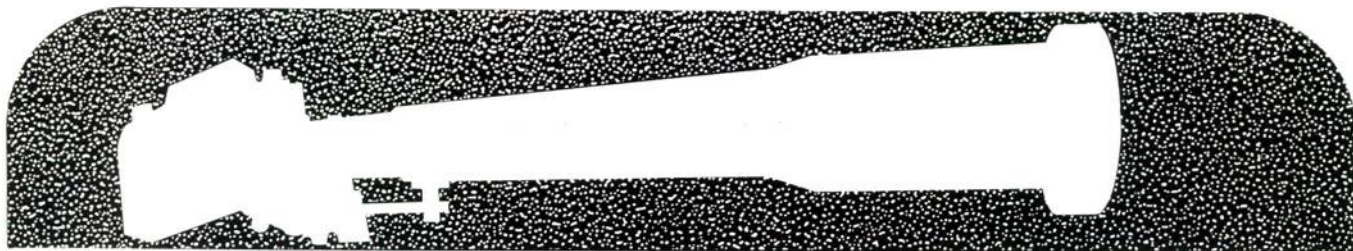
eight frames



single frame print



four frame integration print



Printing Your Astrophotographs

Part 4

Integration Printing and High Contrast Photocopying

by

David Hudgins

Astrophotographers tend to be a hardy and persistent lot! They'll endure hours of frigid temperatures, endless frustrations with equipment, mosquitoes, suspicious neighbors, barking dogs and loneliness without hesitation for a few treasured photos. But what can you do on starless nights when your boundless enthusiasm can't even part the clouds? Nights like these are for perfecting your printmaking ability; in many ways, darkroom skills are just as critical to a fine astrophoto as is your telescope work! Two powerful and increasingly popular astrodarkroom techniques really worth trying are *integration printing* and *high contrast photocopying*.

These techniques can greatly improve your deep sky photos. Don't let the exotic sounding names throw you off, and don't assume that these methods are just for the few with sophisticated telescope and darkroom equipment. The truth is that integration printing and high contrast photocopying most dramatically benefit very modestly equipped city astrophotographers. If you are lim-

ited to piggyback sky shooting, the grain reducing effect of integration printing will permit greater enlargement of those tiny images of nebulae and galaxies that result with most telephoto lenses. For the frustrated city astrophotographer, these techniques open new opportunities for deep sky work because of their ability to enhance the faint detail recorded during necessarily short exposures.

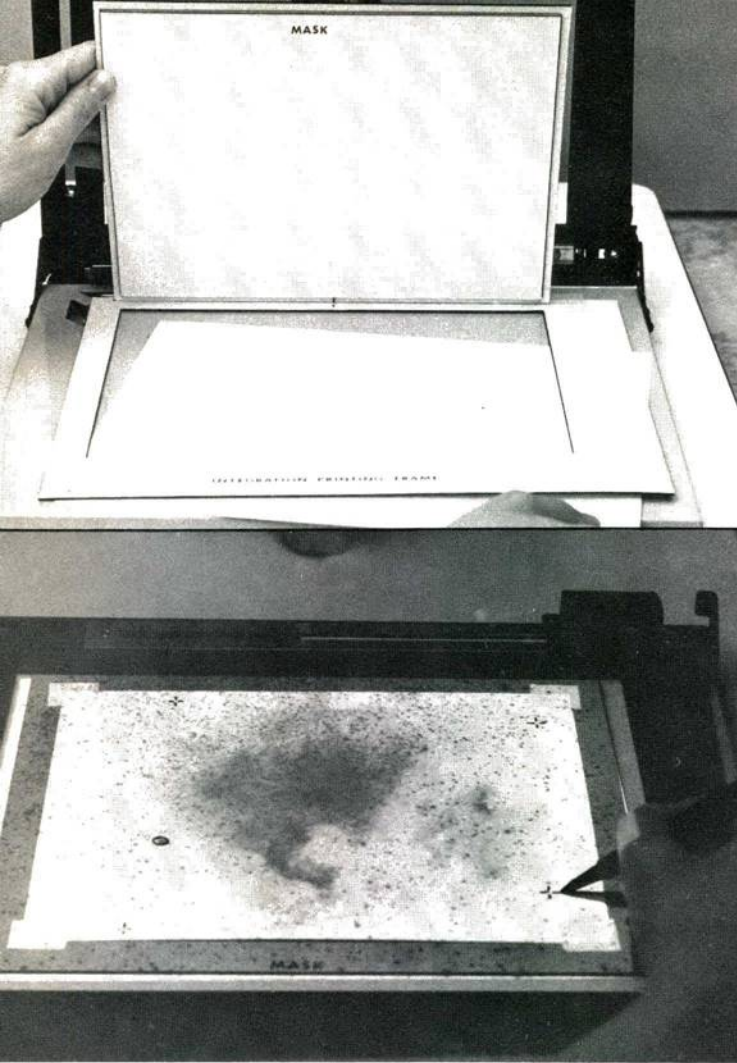
Briefly, integration printing and high contrast photocopying are methods of averaging the coarse grain typical of the spectroscopic films used for deep sky work, and then raising the contrast levels by photocopying to better separate dim stars and faintly recorded nebulosity from the dark background. The techniques are not always used together; integration printing is often all that is needed to make dramatic improvements in a photograph. In some situations, high contrast photocopying can make further improvements, but this technique is rarely successful on deep sky photographs that have not been smoothed out by integration first.

Integration Printing

Basically, integration printing is the technique of producing a single finished photograph from the superimposed images of two or more identical negatives; the purpose is to reduce the graininess of the image. Grain is made from the tiny particles of silver that form the image, but which also tend to camouflage faint detail and dim stars. By superimposing a series of negatives, the sharp grain edges "average out". This smoothing effect increases with the number of negatives used, but is very apparent with as few as three frames.

Simply, the procedure involves placing several

Top left: A single negative print of Saturn may be sharp, but grainy. **Top right:** By integrating four images, graininess is drastically reduced. Both pictures were taken with an eight inch Newtonian at f/80, with a four second exposure on SO-410 film. Photographs by Howard Zeh. **Middle row:** Prints with one through eight negatives integrated show more and more detail and less grain. What is the best number of negatives to integrate? That's your choice! The Crab nebula negatives were made with a 10 inch f/5.6 Newtonian; exposures were nine minutes each on 103aE spectroscopic film. **Bottom:** Integration printing can benefit every astrophotographer! The Rosette nebula was recorded from suburban Kansas City using a piggybacked 400mm f/6.3 telephoto lens with a #25 red filter for a 20 minute exposure on 103aE film. At left is a single negative print, while at right four negatives have been integrated. Photographs by David Hudgins.



negatives — one at a time — in your enlarger. You'll carefully position each with respect to reference marks locating bright stars, and then make a brief exposure using each negative.

The only equipment you will need are a simple frame and mask like the ones shown on page 36. Make them from thin — but rather stiff — cardboard (such as photo mounting board), and then tape the frame to a printing easel. The frame makes the white border around the print, but more importantly it holds the mask and attached reference sheet in *exactly the same position* over the photo paper to assure exact alignment of stellar images.

After making the frame and mask, you're all set to begin. The inevitable first question is, "How many negatives do I need?" The answer depends on how much the negative is to be enlarged, whether you intend to use high contrast photocopying to increase faint detail, and finally on your own personal tolerance for grain. As few as three negatives may be satisfactory for a full frame 8 x 10 inch print that will not be used as a master for high contrast photocopying. In extreme cases, you may find it worthwhile to use six or eight negatives if the image scale is so small that a considerable amount of enlargement and cropping of the negative will be required.

Figuring how many negatives you need should

Top left: To make integration prints, you must construct a simple printing frame that allows you to expose the paper to successive negatives. Bottom left: With the flap down, carefully mark the positions of several prominent stars on the reference sheet. Right: The setup for making copy photos is very simple. You'll find copying allows you to add snap to your astronomical photos. Photographs by David Hudgins.

be part of your planning before you begin taking the pictures — not in the darkroom the next day. Always try to take at least one or two extra exposures as a safety factor against guiding errors or other misfortunes. If you want to try integrating four frames, shoot five or six exposures at the telescope.

What should you look for in selecting negatives for integration printing? First, each should be a well-guided exposure capable of producing a fine print all by itself. Second, the fog level of each negative should be very nearly equal to avoid complicating the calculation of exposure times for the printing operation. Finally, accurate registration or alignment of star images is much easier if the negatives themselves are sharply focused. Big mushy star images are hard to align precisely, and in any case poorly focused negatives lack the hidden detail that integration is meant to reveal.

After selecting your negatives, place the first one in the enlarger and adjust the image scale to best portray the subject. Focus carefully on the back of an exposed piece of photo paper held tem-

porarily in the integration frame. Next, set the integration mask in the frame and mark the positions of several bright and dim stars on a piece of white paper taped to the mask. Now remove the mask and make a test strip to find the proper exposure time for a normal print. The photo paper used for both the test strip and the final print should be one or two contrast grades higher than normal to counteract the tendency for integration to reduce apparent contrast. In addition, be sure to stop your enlarging lens down more than normal so that an exposure time of 30 to 60 seconds is required; this avoids excessively short exposures for individual negatives later on.

After figuring the normal exposure time, calculate the "mini-exposures" needed for each of the negatives you plan to use in the integration. To do this, first divide the normal exposure time by the number of negatives. Then add an additional 40 percent to the first mini-exposure and 20 percent to each remaining exposure. For example, if your test strip shows that a normal exposure of 40 seconds would be needed, then a four negative integration would have exposure times of 14 seconds for the first frame and 12 seconds for each of the remaining three frames.

Why do you have to increase the length of these mini-exposures? First, you have to compensate for the *intermittency effect* — a term referring to the fact that photographic materials are not as affected by a series of short exposures as they are by the same amount of light delivered in a single burst. Additionally, the first negative you expose in the printing operation must be given more time to provide the "threshold" energy needed to activate the image recording process in the paper emulsion. This added exposure insures that the first negative contributes equally to the final density of the integrated print.

After figuring the exposure times, put a sheet of unexposed photo paper in the integration frame. To be safe, tape down two corners so that the paper doesn't move relative to the frame during the integration procedure. Set the mask in place, turn the enlarger on, and carefully line up the star images with your reference marks. To get the best alignment, use the large bright star images to roughly orient the frame. Make your final adjustments using the tiny images of two dim reference stars located near opposite sides of the picture.

When you are satisfied with the alignment, turn off the enlarger and carefully remove the mask. Now make your first mini-exposure. From here on, it's just a matter of repeating this operation. Replace the mask, put in the next negative, line up the star images, and make the exposure. One word of caution, however: Check the focus between frames, but don't make any change unless there is a gross error. Even slight changes in focus alter the image scale, causing more harm to the final print than a slight out-of-focus condition

would have. Naturally, if the focus is way off (perhaps from buckling of the negative because of excessive heat), you'll be forced to touch it up. But you might not be able to return the image to perfect alignment after you do so!

After the last mini-exposure, develop the print and examine your results closely. Is the print much too dark? You probably forgot to replace the mask during the process. Are your star images mushy? Be more careful in aligning the reference marks and checking the focus between negatives. Remember that star images — even on a carefully integrated print — are always very slightly softer than normal, but the difference should require close scrutiny to detect.

Don't worry if your first integrated print doesn't turn out just right! Even experienced darkroom workers end up making a number of prints before they're satisfied with exposure, alignment, and any dodging or burning that may also have been required. Fortunately, this is pleasant work and the beautiful results will handsomely repay your persistence.

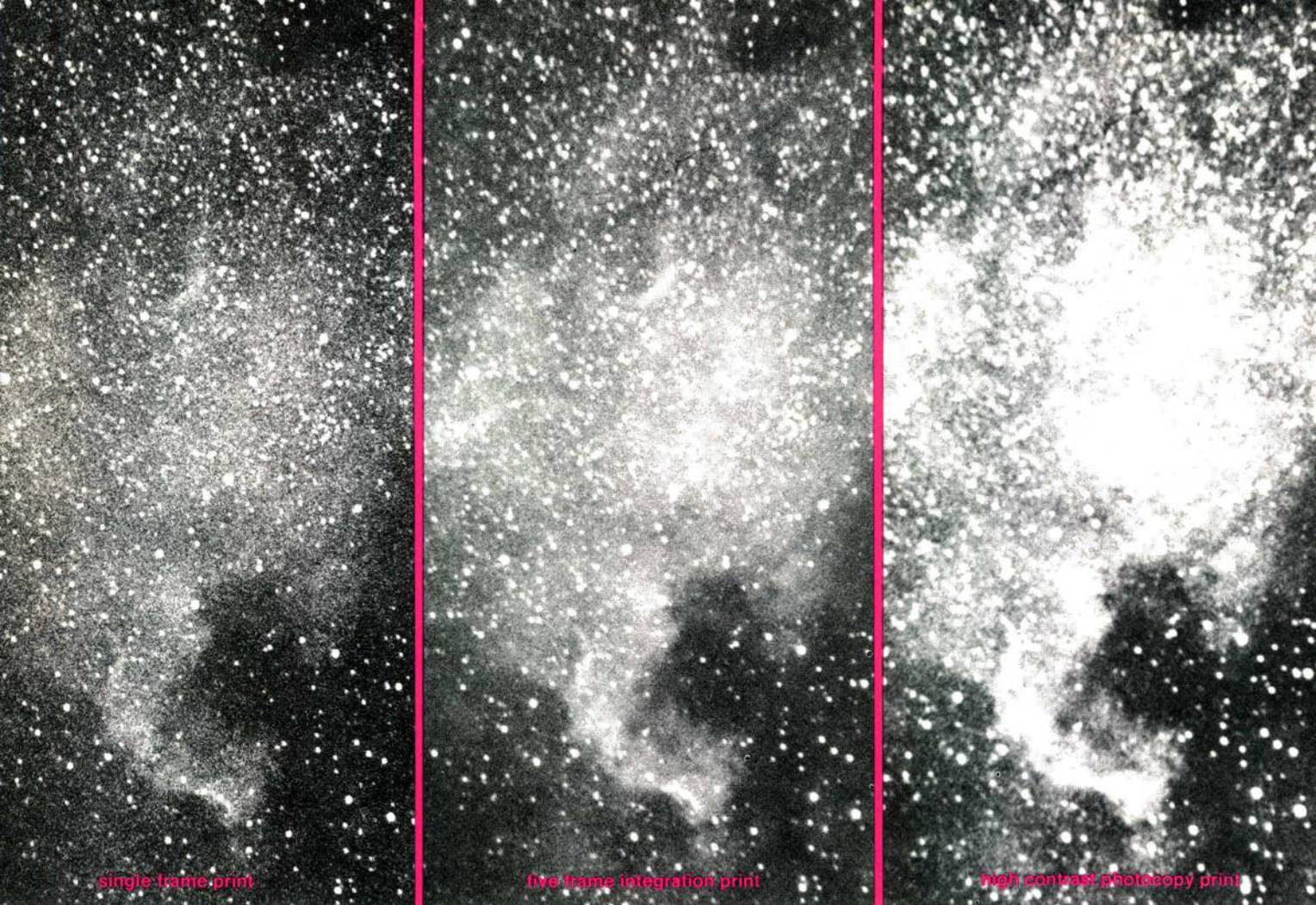
Planetary Integration

Up to this point, we've discussed integration printing strictly in terms of deep sky photography. But wouldn't it also be useful in reducing grain in planetary photos? The most accurate answer seems to be "maybe — in some cases".

There are two main reasons why this technique is not as popular with planetary astrophotographers as it is with deep sky enthusiasts. First, the difficulty in accurately registering several planetary disks without the help of tiny star images limits the ultimate resolution of the final print — no matter how fine the grain becomes. Secondly, the availability of Kodak's SO-410 — and now the new SO-115 — emulsions has gone a long way in filling an otherwise serious gap in 35mm photography for a very fine grained, contrasty, and relatively high speed film.

From a practical standpoint, in most cases it's simply easier to use SO-410 film than to attempt integrating a comparable print from a grainy film like Tri-X. At extreme focal ratios or on a dim planet like Saturn, where exposure times might become too long for your particular seeing conditions or drive accuracy, integration of several of your best short exposures using a fast (but grainy) film like Tri-X may improve results. Naturally, integration printing reduces the grain in any photo — no matter what film is used. If you won't be satisfied with anything but the very best, you may find integration printing of your planetary shots worthwhile, even when using a very fine grained film.

Integration printing of planetary photos is a relatively unexplored area of astrophotography, so you might be among the first to develop the technique. Though there are not many established rules, there are a few tips that seem to improve results.



First, work with a large planetary disk when printing — at least an inch (preferably two inches) in diameter. You can later rephotograph the integrated print to allow adjustment of the disk to any size you like.

Secondly, study the image carefully and draw an imaginary line exactly along the equatorial plane of the planet. Make “tick marks” on the reference sheet (attached to the integration frame) along this line, but just barely touching the extreme outside edges of the planetary disk or ring system. Make a second set of tick marks at the edge of the disk along the polar axis of the planet. It’s easy to locate these reference marks for Jupiter or Saturn, but it’s a lot more difficult for Mars which lacks those features that accurately identify the equatorial plane.

Naturally, if there are any sharp markings on the planet, these should be noted and used as a further aid in accurate registration of the images. But remember that Jupiter rotates rapidly; don’t try to integrate negatives taken over a period of time greater than about 10 minutes, or there will be obvious blurring because of planetary rotation. For high resolution photos, this time frame is even shorter.

Photocopying

Photocopying is a technique that naturally goes hand-in-hand with integration printing. Fre-

Left: Using a piggybacked 300mm f/4 telephoto lens with a #25 red filter, the North America nebula records well even from suburban skies. This is a single-negative print exposed 12 minutes on 103aE film. **Center:** Integrating five frames identical to the one at left reveals detail and nebulosity invisible before. **Right:** High contrast photocopying the five frame integration print enhances contrast and reveals still more nebulosity, but also enhances graininess. Photographs by David Hudgins.

quently it’s just a convenient way of making additional smaller or larger prints without having to integrate each one. By a slight change in procedure, however, photocopying can become a powerful method of raising contrast in an integrated print. This often brings out details and wisps of nebulosity that are otherwise lost in the printing process, and can make spectacular improvements in the dramatic impact of display photos. High contrast photocopying is only possible with the deep sky spectroscopic films *after* integration printing has been used to smooth out the otherwise coarse grain.

By combining high contrast photocopying with integration printing, it’s possible to photograph dim objects that would require considerably longer exposures using normal printing methods. As a result, these techniques are especially useful to city and suburban astrophotographers who are always limited by bright skies to brief exposures normally incompatible with deep sky photography.

Anyone with a camera can make some sort of copy of another photograph, but making a high quality copy negative requires both attention to technique and an understanding of the materials you are working with. You really don't need much in the way of equipment — a camera (preferably a 35mm single lens reflex), tripod, two light sources and a wall.

Probably the single most important factor in successful high contrast photocopying is starting with an original integrated photo that is printed lighter than normal. This reveals the very faintest nebulosity recorded on the film. In addition, you should "burn in" denser parts of the negative (see "Basic Printmaking" and "Printmaking Tricks" in the December 1976 and January 1977 issues of *ASTRONOMY*) so that structural detail is printed in even the brightest and innermost parts of the nebula or galaxy.

Load your camera with a roll of Panatomic-X film, and mount it on a sturdy tripod. Tape the master photo to a wall so that its center is at the same height as the camera lens. By keeping the photo exactly "square on" with the optical axis of your camera, focusing is simplified and distortions due to a slanted perspective are eliminated (see the photograph on page 36).

Place your camera so that the master photo fills almost the entire frame. Most 35mm single lens reflex cameras have lenses that focus down to about 20 inches, but this may still not allow you to get close enough to fill the frame unless your master photo is rather large. Extension tubes are probably the best way of allowing closer focus and larger image scale. On the other hand, you may already own one of the 1.5 or 2 power teleextenders which can be coupled with your regular lens to greatly enlarge the image scale. Be sure to stop your regular lens down to at least f/5.6 though, because most teleextenders do horrible things to image sharpness at lower f/stop settings.

Even illumination of the master photo is a critical requirement, especially for high contrast photocopying. If the lighting isn't even, it's almost impossible to make a good print from the copy negative. The simplest lighting setup uses two light sources on either side of the master photo, at 45 degree angles from the lens axis as shown on page 36. This provides even lighting and also minimizes reflections of the light off the glossy surface of the master photo back into the camera.

Before actually taking the picture, carefully examine the master photo through the camera viewfinder if you use a single lens reflex camera. Look for faint reflections on the black glossy surface. About the only way to control these secondary reflections is to work in a darkened room (except for the two off-axis lamps), and to hide yourself and the shiny parts of your camera and tripod behind a large piece of black construction paper. Poke the camera lens through a hole in the paper. Don't

waste any film or processing time by shooting before you eliminate all reflections on the master photo!

The next step is to determine the exposure time. You can't just take a light reading off the master photo — all that dark background will throw the light meter way off. The best way is to use a neutral gray test card (available from photo stores for about \$2); these cards reflect the same amount of light as an average scene. Simply hold one of these cards in place over the master photo while you determine the normal exposure with your camera lens set at about f/5.6. This normal exposure should be the midpoint for a wide bracket of actual exposures ranging from 1/4 to 4 times that value. For instance, if the meter indicates a 1/60 second exposure, also try 1/15, 1/30, 1/125 and 1/250. By bracketing your exposures, you'll be sure to get at least one frame with the right degree of density.

Check the focus carefully. You may find it helpful to stretch a piece of fine white thread across the center of the master photo, temporarily attaching it to the wall with masking tape while you focus.

After following all the steps outlined above (firmly mounted camera, even lighting without glare, and sharp focus), you are now ready to make a series of bracketed exposures. Use a cable release to minimize vibrations.

The processing of the exposed Panatomic-X film depends on whether you want a high contrast photocopy or merely a faithful reproduction of the original. For a simple duplicate, use a general purpose developer like HC-110, but *reduce* the developing time by 15 percent to counteract the natural tendency for photocopying to increase contrast. On the other hand, to raise the contrast of the integrated print to show maximum nebulosity, you should *increase* processing time in a normal developer by 25 percent for a moderate contrast increase. Even higher contrast is possible by using D-19 developer for five minutes at 68 degrees Fahrenheit, but this can be easily overdone.

A high contrast photocopy naturally tends to emphasize grain to some degree, right along with the extra nebulosity. A three or four frame integration counteracts this process, however, revealing considerably more faint detail while keeping grain at a very moderate level.

An inescapable fact about the darkroom techniques described here is that they take extra time and care. For most of us though, astrophotography is a hobby — a pleasant way to enjoy astronomy and the incredible universe around us. So what if these techniques take a bit more time! A few fine photographs that you can really take pride in are worth more than dozens of mediocre shots. So why not give these methods a try? Just be ready to set a new and higher standard for your own future astrophotos! 📸

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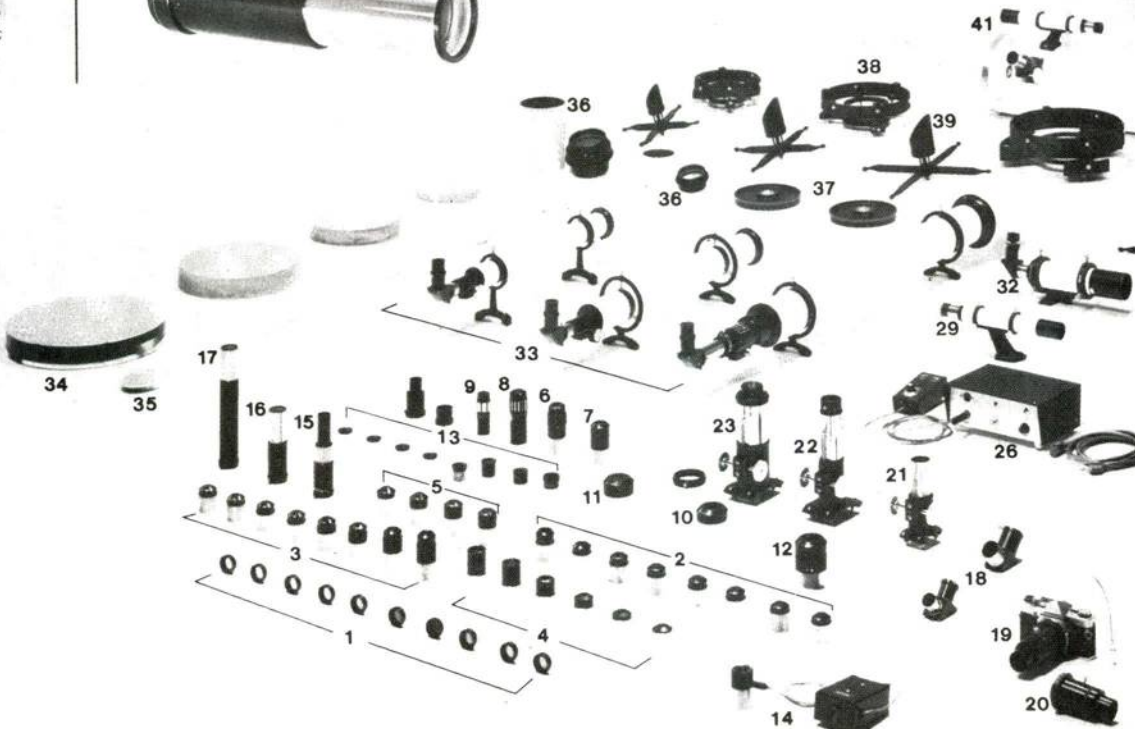


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by

Henry J. Phillips

If you're just getting started in astronomy and you're having trouble finding your way around all those stars you see in the sky, it's time you began learning the constellations. You can enjoy the sight of a lovely starry night without knowing the constellations, of course. But once you begin to get acquainted with the constellations — learning their titles, patterns, and the names of their brighter stars — you'll find it's a lot more fun. Constellations soon become old friends, and since different star groups are associated with the different seasons, you'll derive even more pleasure from watching the constellations announce the coming of spring, summer, fall or winter.

In addition, learning the constellations is essential if you plan to go deeper into observing. Each of those magnificent objects that you see photographs of is located in a specific constellation, and if you want to find them, you must know where to look. Why not begin now to find your way around the sky? The stars are available any clear night for your inspection and enjoyment.

When you start looking into the sky to learn the stars, the first and most obvious thing you'll notice is that stars have different brightnesses. Your eye will be drawn to the brightest stars first,

and they'll be the easiest to remember. The brightest stars are called *first magnitude stars*.

A star's magnitude is a measure of its brightness. A typical first magnitude star is 2-1/2 times as bright as one of second magnitude, which in turn is 2-1/2 times as bright as a third magnitude star, and so on. Sixth magnitude stars are at the limit of naked eye visibility, and are 1/100 as bright as first magnitude stars. Of course, very few stars are *exactly* first magnitude, second magnitude, etc. Magnitude measurements are refined to the point that stars have magnitudes like 0.41, 1.58, 2.12, and so on. Nevertheless, the old arbitrary classes are handy to use. There are 21 first magnitude stars, and they all have individual names that help you remember them.

Another difference between stars is their color. They aren't all silver or white, like they seem at first glance. Look more carefully, and you'll see that some are red, some are yellow, orange, white or blue. Take a look at red Betelgeuse and blue Rigel at opposite corners of the constellation Orion, and the difference will show plainly. The colors of the brightest stars provide another useful identification tag.

The best way to learn the constellations is to go



Orion is the most magnificent of the winter constellations, containing many bright stars in a small area. The brightest are Betelgeuse (the red star at the upper left corner of the rectangle) and Rigel (bluish, at lower right). The stars of Orion's belt serve as pointers to many other bright winter constellations, including Taurus (see the photo in this month's *Sky Almanac*). This is a 10 second unguided exposure made with a 50mm lens.

outside with a star map — our monthly Star Dome map is a good example — and compare the patterns on the map with the stars in the sky. If you see a bright star that isn't on the map, it's probably a planet. Planets are always located in the constellations of the zodiac; we'll indicate which these are in the following short description of the winter sky.

The best starting point for any introduction to the winter constellations is **Orion** (pronounced oh-RYE-on). When you step outside at about 9 p.m. on a winter evening, you can identify Orion instantly — nothing else in the sky remotely approaches it in the number and distinctive arrangement of its bright stars! Look for a rectangle marked at each corner by a bright star, with a line of three stars in the middle. Orion looks like a man (in mythology he was a hunter); the stars at the top of the rectangle mark his shoulders, those at the bottom are his knees, and the three stars in the middle are known as Orion's belt.

Two of the stars in the rectangle are first magnitude: *Betelgeuse* (BET-el-jooz), in the upper left

hand corner of the rectangle, and *Rigel* (RYE-jell), at the lower right. Rigel is usually the brighter of the two, but Betelgeuse varies in luminosity over a period of several years and sometimes is just as bright as its neighbor. You can also identify the two stars by their colors: Betelgeuse is a deep red, while Rigel is brilliant blue.

Some of the other stars in Orion have names too. The star at the upper right corner of the rectangle is *Bellatrix* (BEL-a-trix), and at lower left is *Saiph* (SAY-if). These stars and those in Orion's belt are all blue or bluish-white in color, like Rigel. Together they add up to the most superlative collection of stars in the entire heavens.

Once you've located Orion, you can use its stars as pointers to many of the other prominent constellations surrounding it. The three stars of Orion's belt point up to the zodiacal constellation **Taurus** (TOR-us), whose brightest star is the orange luminary *Aldebaran* (al-DEB-a-ron). Aldebaran is at one end of a V-shaped group of stars — not a constellation in themselves, but a large star cluster called the **Hyades** (HIE-a-deez). Aldebaran itself is not a member of the cluster, but it lies in the same direction as seen from Earth. Also located in Taurus is an even more famous cluster, the **Pleiades** (PLEE-a-deez). Also known as the "Seven Sisters", the Pleiades cluster contains several naked eye stars in a tiny area of the sky. Some

people can distinguish eight or nine stars in the Pleiades with the naked eye, while others can see only six. How many can you see?

In ancient legends, Taurus was said to represent a bull. You can see its "horns" by extending the V of the Hyades out to two second magnitude stars; the northernmost of these two is called *El Nath*. As the stars slowly move across the sky from east to west, you can see Taurus the bull slowly backing away from Orion the hunter in a battle that takes place annually.

El Nath leads us to our next winter constellation, **Auriga** (or-EYE-gah). We can "borrow" El Nath from Taurus to complete the pentagon that is Auriga's distinctive pattern. The brightest star in this pentagon is *Capella* (ka-PEL-ah), a yellow object that is very much like our sun in composition. Capella is at the top of the pentagon; it's sometimes called the "Goat Star", and three fainter stars near it are called the "Kids".

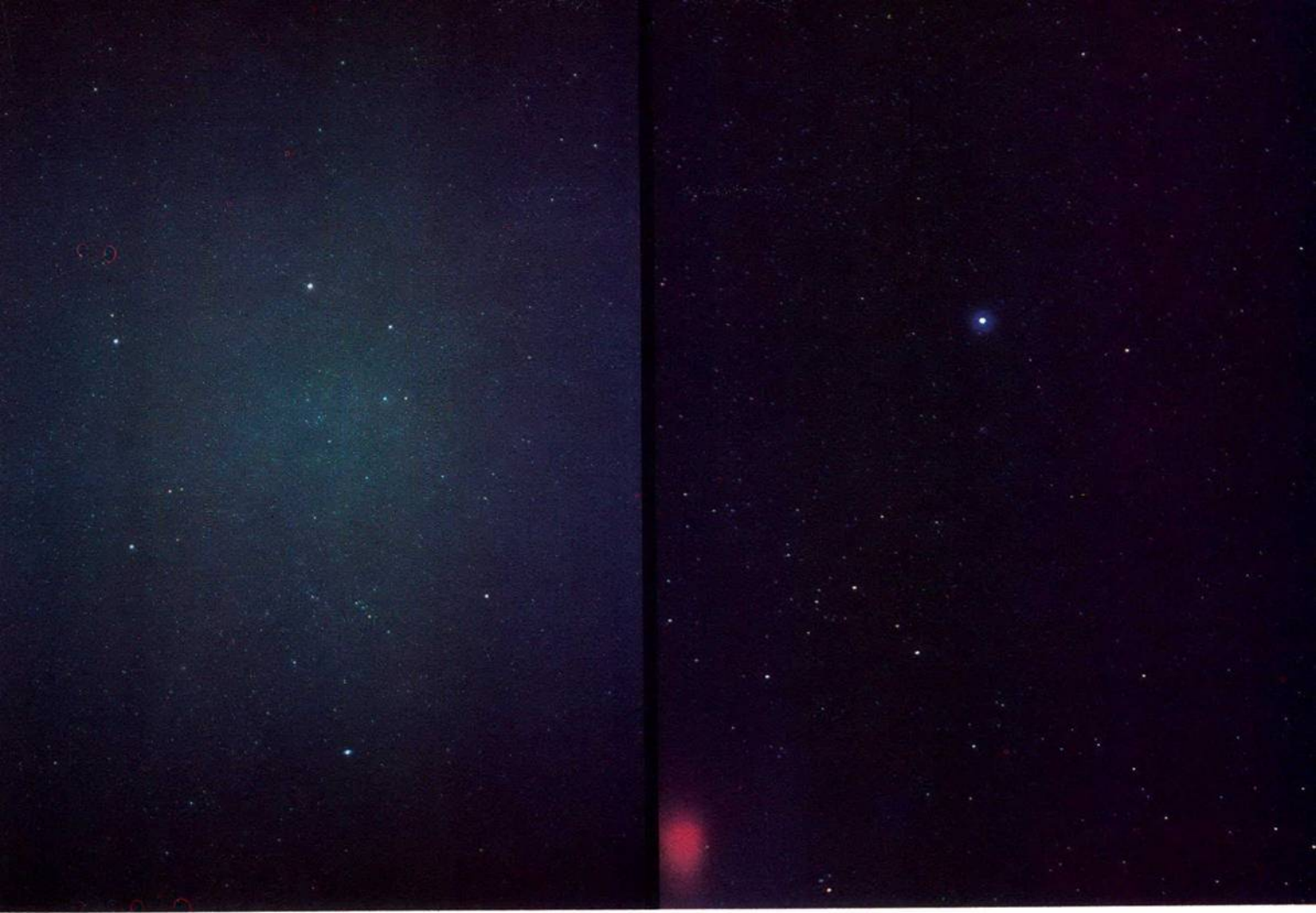
Let's return to Orion, our trusty guide to the winter stars. The belt stars, which we used to locate Aldebaran, point in the opposite direction to an even more brilliant and famous star: *Sirius* (SIR-ee-us), the brightest star of all. You can't mistake Sirius, as it outshines every other star in the sky. Its light is clear white with just a tinge of blue. Sirius is so dazzlingly bright that it pretty well outclasses everything else in the constellation **Canis**

Above: Gemini, one of the most prominent winter constellations, is in the zodiac where the moon and planets travel. Its two brightest stars are Pollux and Castor. This 10 second unguided exposure was made with a 50mm lens. Opposite, left: The yellow star Capella, second brightest of the winter stars, is the leading light in the constellation Auriga, whose pentagonal shape is among the most distinctive of star patterns. A 50mm lens at f/1.8 was used for this eight minute exposure. Photograph by L.H. Price. Opposite right: Canis Major contains Sirius, the brightest star in the sky, as well as many other bright stars. This is a 10 minute exposure, made with a 50mm lens at f/2.8. Photograph by Robert Gewin.

Major (KAY-nis MAY-jor), where it is located. However, Canis Major does contain many other bright stars. If you live in the southern United States where it rises higher, it will stand out more strongly, undimmed by horizon haze.

As Capella is the goat, so Sirius is the dog; its popular name is the "Dog Star", and in ancient times it was thought of as Orion's dog following him faithfully across the sky. There's another dog star in the sky, too, which forms one corner of an equilateral triangle with Sirius and Betelgeuse: *Procyon* (pro-SIE-on), a yellowish-white star in the constellation **Canis Minor**. Procyon is the "Little Dog Star" (perhaps today we could call it the "Puppy Star"). Canis Minor contains just one other naked eye star — which may be one reason it was thought of as Orion's smaller dog!

Between Canis Minor and Auriga is another zodiacal constellation: **Gemini** (JEM-in-eye). Its



two brightest stars, *Castor* (KAS-tor) and *Pollux* (POL-ux), are close together and almost equally matched in brightness — so from olden times they have been called the “Twins”. Pollux is orange and slightly brighter than Castor, which is yellowish. Castor and Pollux mark the twins’ heads; the rest of their bodies extend southwest toward Orion, and two or three fairly bright stars are in the “feet” halfway between Betelgeuse and the twin stars.

Two other star groups deserve mention, although they contain no particularly luminous members. The small constellation **Lepus** (LEE-pus) lies just south of Orion; it’s marked primarily by a quadrangle of third magnitude stars, and it’s not difficult to find below Rigel and Saiph. Ancient legends said it represented a hare that Orion was hunting before he was transformed to the sky. Much larger than Lepus is the constellation **Eridanus** (air-i-DAH-nus), named after a river in Greek mythology. The source of this celestial river is near Rigel; it flows westward before making a long curving swoop to the southeast, doubling back south, and going below the southern horizon for all but the southernmost U.S. [where fortunate observers can see the first-magnitude star *Achernar* (AH-ker-nar) that marks the river’s mouth]. Although it contains no other stars brighter than third magnitude, Eridanus is an impressive constellation — especially from the latitude of Hawaii,

where its long sweeping curves, seen all at once, are a majestic sight.

All in all, our winter constellations put on quite a spectacular show; nowhere else in the sky are so many first magnitude stars concentrated in such a small area. Capella, Pollux, Procyon, Sirius, Rigel and Aldebaran together form a gigantic “great circle” of bright stars that is characteristic of winter; in the center of the circle (approximately) is the red star Betelgeuse. Running through the circle is the winter Milky Way — fainter and less impressive than its summer counterpart, but useful nonetheless for identifying the star groups along its path and on its fringes.

Remember, if you want to learn the constellations, there’s no alternative to going out as often as possible and looking at the sky. It’s easy to stay inside during cold winter nights; of course, we don’t recommend that anyone stay out so long in subzero temperatures that frostbite sets in! But during those really inhospitable nights, you can go over your star map and memorize the constellation’s shapes. Be prepared for the first evening that you step outside and find — lo and behold — Orion and all the rest are really up there! 🐾

Editor’s note: This is the first installment of a four part introductory guide to the constellations. Other articles will cover the spring, summer and autumn groupings in March, June and September.

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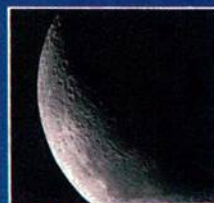
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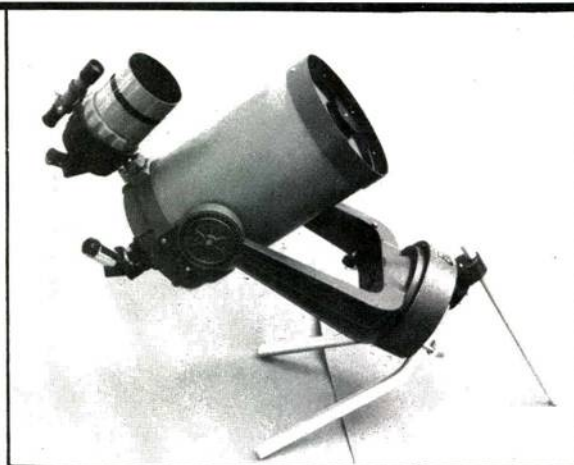
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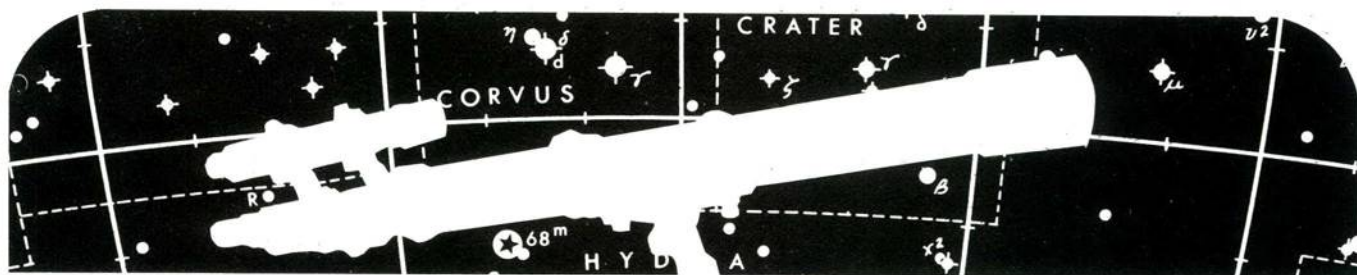
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EQUIPMENT ATLAS

TUNING IN ON RADIO ASTRONOMY: BUILDING YOUR OWN RADIO TELESCOPES

by

Debra Meloy Elmegreen

For decades the realm of observational astronomy has captured the evenings of astronomy enthusiasts all over the world. A serious observer can make an enjoyable — though small — contribution to many fields through systematic long-term observation of objects such as variable stars, sunspots or planets, or by chance discovery of objects like comets. Usually a small optical telescope, good skies, and lots of patience are all that are required for successful study.

What many observers don't know is that they can enjoy doing *radio* astronomy as well. It isn't necessary to have lots of fancy equipment and a radio operator's license (although hams often discover astronomy through this door). A completely functional radio telescope can be built as cheaply and as simply as a homemade six inch reflector, and in the same amount of time.

But why turn to radio astronomy? It's fun, because a totally new observing window opens to you. One appealing aspect is that you can observe in the daytime as well as at night. Remember that radio waves don't "care" how bright it is outside. And cloudy skies won't interfere; radio waves easily penetrate clouds. The only disadvantage to daytime observing is that there are a lot more radio stations operating in the day than at night, which adds noise to cosmic radio reception. However, Jupiter and our sun are the prime subjects for home radio astronomy. And since they are much stronger radio emitters than any other object at decameter (tens of meters) wavelengths, we can still hear them above the background noise.

Most people are familiar with the big radio telescope "dishes" — the parabolic reflectors covered with a chicken wire type of mesh or metal plates. These operate in the same way as a concave primary mirror in an optical telescope, bringing radio rays to a focus where a receiver (analogous to the eye or a photographic film in optical work) is

located. The radio dish needn't be made of aluminized glass, because radio wavelengths are very much longer than visual wavelengths — by a factor of a billion or so! Thus the crude looking surface of a radio dish is actually very smooth and shiny at radio wavelengths. The surface of such dishes must be made of material finer than chicken wire for centimeter (tenths of meters) wavelengths — such as metal door screen. But if we're interested only in decameter wavelengths, then the mesh can be even more widely spaced. In fact, we can have a big open wire antenna! So let's begin by seeing how to build a simple radio telescope suitable for decameter studies of objects like Jupiter and the sun.

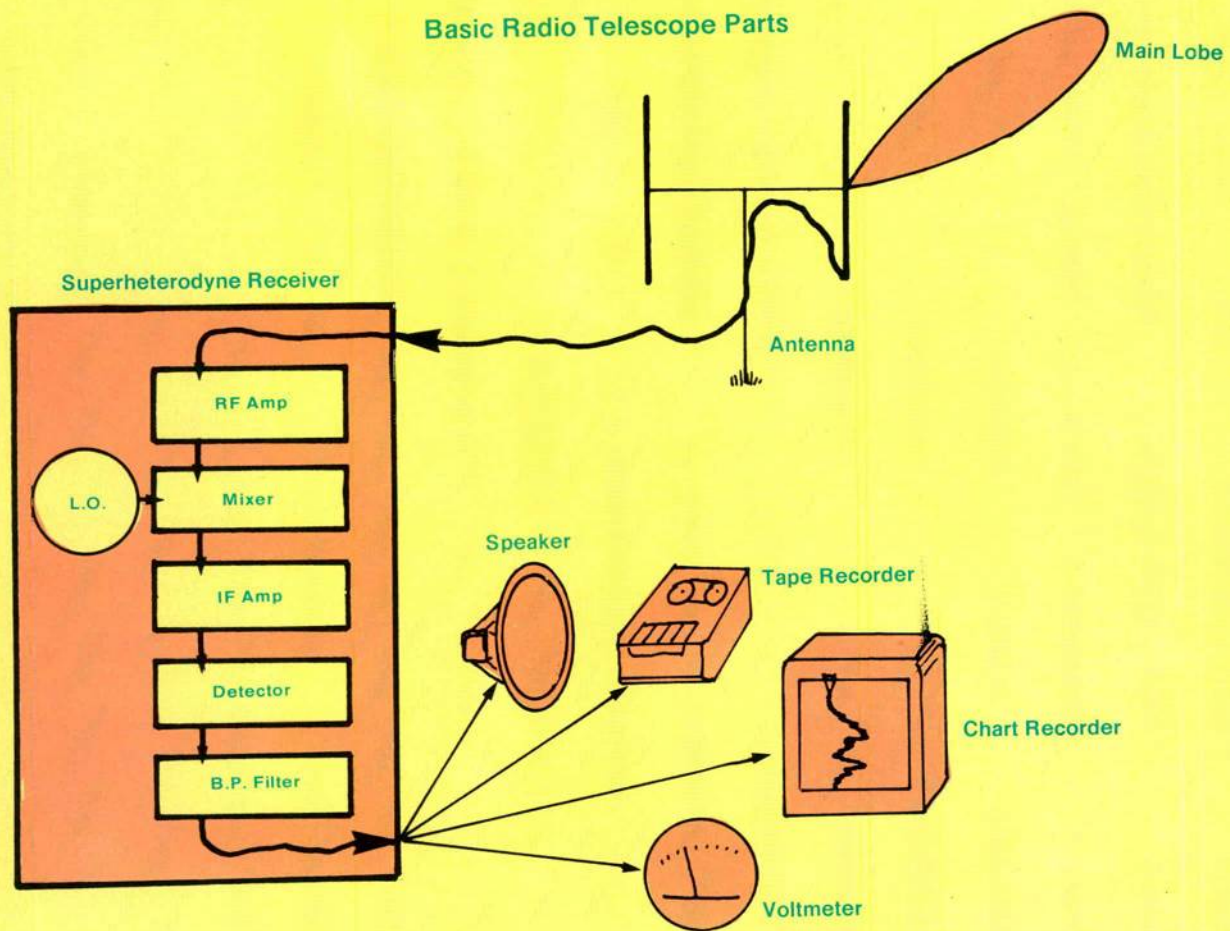
A radio telescope consists of a two main components: an *antenna* and a *receiver*. We'll consider each in turn.

Antenna

The simplest, most convenient, and most economical antenna for our purposes is called a *cubical quad* antenna. There are three main reasons why this design is well-suited for listening to Jupiter or the sun: 1) The cubical quad is relatively small; 2) It works best for astronomical purposes when it's suspended close to the ground, and 3) It's semidirectional.

A cubical quad derives its name from its geometry; it consists of two square arrays or elements, each having a perimeter of one complete wavelength at which you want to observe, or $1/4$ the total wavelength per side. The two elements are separated by $1/4$ wavelength as well. The form is, basically, the outline of a cube, and the cube is supported $1/4$ wavelength above the ground. Signals from the sky come in and reach both elements. The second element receives a signal which is 90 degrees ($1/4$ wavelength) out of phase with that reaching the first element, because the signal has to travel an additional $1/4$ wavelength before it arrives at the second element. The wave then under-

Basic Radio Telescope Parts



goes a phase change of 180 degrees ($1/2$ wavelength) when it bounces off the second element. The signal is then reflected back to the first element. When this wave returns to the first element, it is an additional 90 degrees out of phase with that arriving at the first element, because it has traveled yet another $1/4$ wavelength. This means that when it arrives back to the first element, its phase has been changed by a total of 360 degrees (90 degrees for each of two traversals, plus 180 degrees upon reflection), or one full wavelength. It's thus exactly in phase with the signal originally received by the first element, so the amplitudes of the two waves add constructively; the signal is enhanced. The system is said to be *in resonance* in this case.

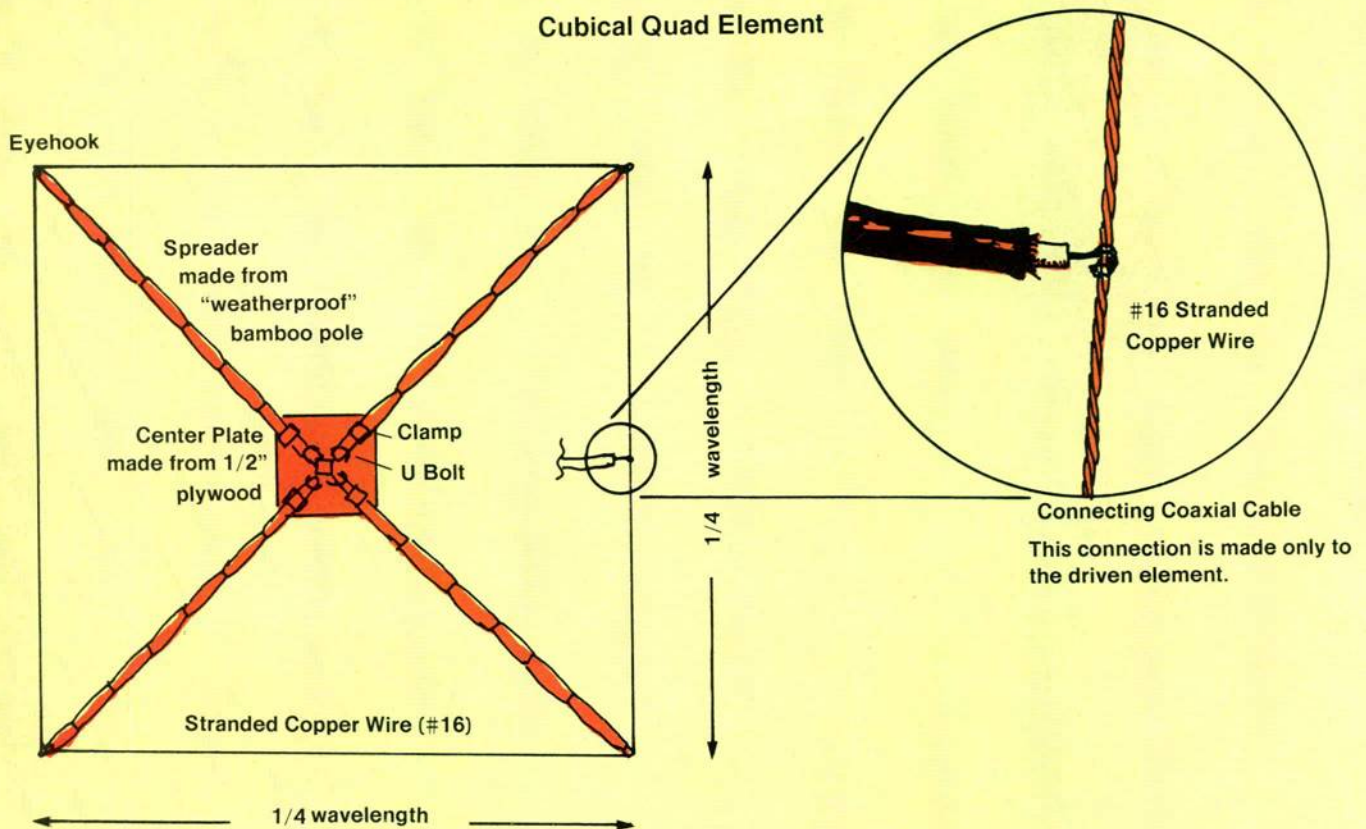
The ground acts as a reflector in a similar way. When the antenna is held $1/4$ wavelength above the ground, there is a resonance between the first element and the ground for the same reasons that the first and second elements are in resonance. By placing the antenna $1/4$ wavelength above the ground, the *directivity pattern* or *antenna pattern* is aimed into the sky. The directivity pattern determines where most of the radio signal will be received, and the region of highest sensitivity is called the *main lobe*. Thus the main lobe is the region of sensitivity for receiving a signal. The main lobe for a cubical quad antenna is inclined at an elevation angle

which is *higher*, the *lower* the antenna is above the ground. Ham operators put their cubical quads high above the ground, so that when they send or receive a signal, it's broadcast nearly parallel to the ground instead of being sent off into space where other hams can't hear it.

However, for astronomers, the higher the main lobe is, the better. You'll want to observe objects when they are relatively high above the horizon so that there isn't as much interference from Earth based objects and manmade signals. It turns out that if a cubical quad is $1/4$ wavelength above the ground, the main lobe — and thus your radio telescope's greatest sensitivity — lies at an elevation of 40 degrees. The peak-to-peak (horizontal) beam-width of the lobe is about 75 degrees. This means that you can listen to objects which are roughly 40 degrees high for a few hours as they drift through this main lobe of the antenna.

To know what size to build your antenna, you must first decide what frequency you want to be able to receive the best. It isn't too fussy — you can receive a signal which is approximately five MHz (megahertz, or millions of cycles per second) higher or lower in frequency than the frequency for which the antenna is built. This is because the system can still be close to resonance for wavelengths which are close enough to the primary one. If the wavelength differs too much from the one for which

Cubical Quad Element



the antenna is built, reflections from the second element and ground will lead to destructive interference of the waves, and your signal will be wiped out.

The sun radiates at all frequencies and has many radio bursts in the decametric range. Jupiter's decametric emissions have been recorded between about 10 and 35 MHz, with peak activity at about 18 MHz, which we'll use as our example. We want to convert this frequency to a wavelength, so we use the formula $\lambda \text{ (meters)} = c \text{ (meters per second)} \div \nu \text{ (cycles per second)}$, where λ is the desired wavelength, c is the speed of light (3×10^8 meters per second), and ν is the chosen frequency. So 3×10^8 meters per second divided by 18×10^6 cycles per second is 16.67 meters, or 54.6 feet. One side of the cubical quad is $1/4$ wavelength, so divide this result by four. This means that the sides of the elements, separation between elements, and height of the antenna above ground are all 13 feet 8 inches.

The antenna structure consists of several basic parts: the square arrays are the *elements*, which are separated by a *boom* and elevated above the ground by a *mast*. The elements are made up of *spreaders*, which are held in place by a *center plate* to form a *spider*. The spreaders form the network around which the antenna wire is wound. The first element, attached to the coaxial cable which relays

the signal to the receiver, is called the *driven element*. The second one, which reflects a signal back to the first, is called the *parasitic element*. We'll discuss the construction of each of these parts separately.

The spreaders should be made of a durable, nonmetallic, lightweight material. Fiberglass fishing rods are one possibility; bamboo poles are excellent as well.

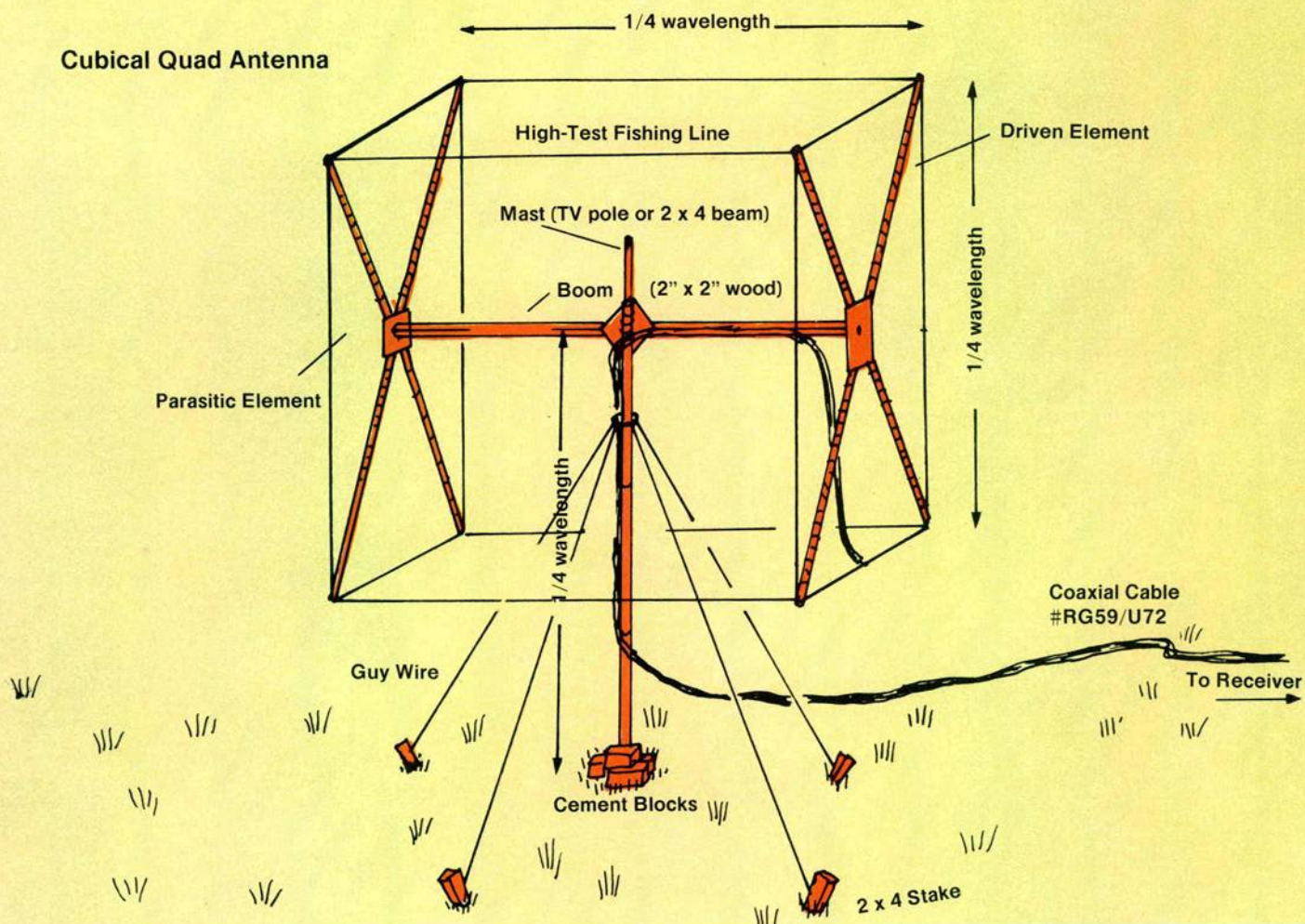
There are three center plates involved in the antenna — one for each element, and one in the center of the boom to attach the assembly to the mast. The element center plates can be made of $3/8$ or $1/2$ inch thick plywood, cut into one foot squares. The central plate, or "diamond" since the square is turned 45 degrees in the assembly, should be of $1/2$ or $5/8$ inch thick plywood, also one foot square (see the diagrams above).

The boom can be a 2x2 inch piece of wood, cut to a length which is $1/4$ the chosen wavelength. The boom cannot be metal, or you may have problems with residual resonance effects created by its presence.

A telescoping television mast two inches in diameter (which you can buy at an electronics shop for your TV antenna) is ideal for the main mast, because of its strength and adjustable height.

It is essential to weatherproof your antenna before you put it up. Bamboo can be protected by

Cubical Quad Antenna



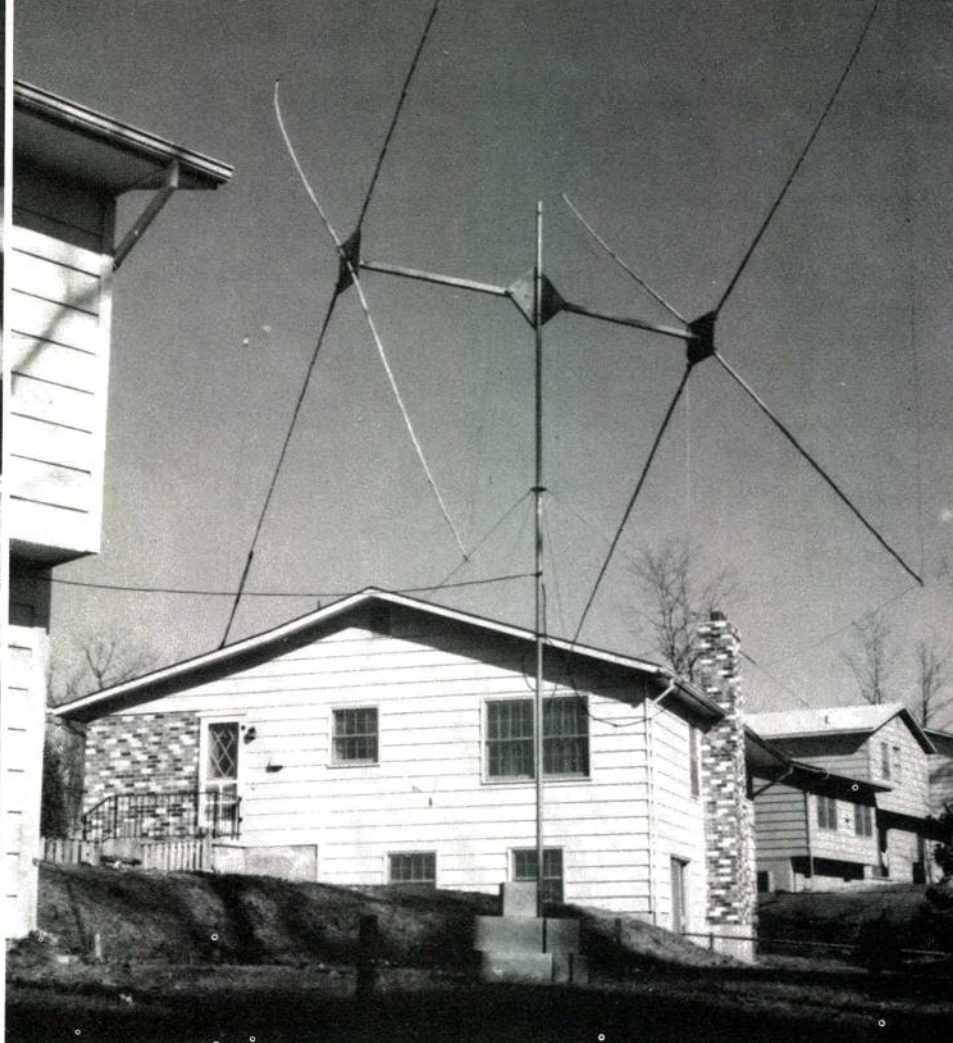
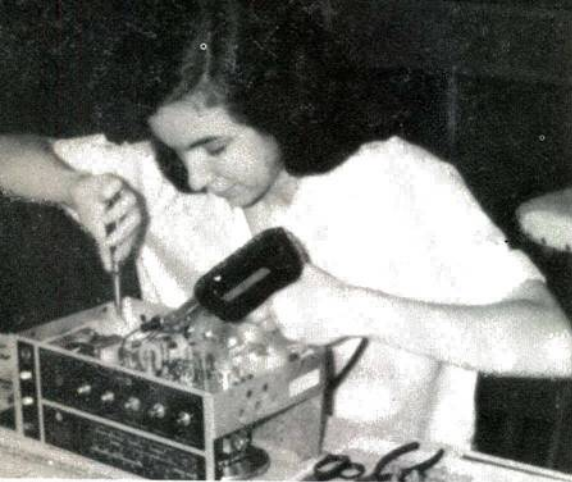
wrapping the poles in gauze, and then painting them with shellac. Any wood pieces should be painted or varnished as well. It's preferable to buy galvanized metal whenever metal parts are necessary to eliminate rusting. Your antenna should remain in good condition for about a year of continuous exposure if you take these precautions.

With all the components organized, you can begin assembling your antenna. Four spreaders are used for each element; each spreader forms half of a diagonal so that the outline of a square can be made. This means that the total length from the end of one spreader to the end of another which is in line with it (the two being attached to the diagonals of the center plate) is the square root of two (1.414) times $1/4$ wavelength. The spreaders are attached to the center plate by means of clamps and U bolts which are mounted on the diagonals of the plate. Drill holes for one clamp and one U bolt for each spreader. In a flat open space, place the center plate on the ground and fasten each spreader to it. Attach an eyehook to the end of each spreader, using strong electrical tape. The antenna wire should be a single piece of thin copper wire, such as stranded #16 copper wire. Loop it through each eyehook. To make sure that the dimensions are correct, mark off each $1/4$ wavelength on the wire using the electrical tape. Each mark should fall at an eyehook if the spreaders are the proper length. Solder the free

ends of the copper wire together in a neat joint. Remember that the copper wire is the most crucial part of the whole assembly; it receives the signal, and everything else is just required to hold the wire in the proper position. Follow the same procedure for the second element.

Fasten the boom to the center plates using angle brackets or bolts going all the way through the boom and the central diamond. Attach the boom to one center plate and the central diamond (see the illustrations on page 54). The mast can be connected to the central diamond by U bolts — one at each end of a diagonal which will then be put in a vertical position. Slip the mast through the U bolts and secure it while the element is still on the ground. Then the structure must be carefully hoisted into place — you'll find you need at least two pairs of hands! Bury the base of the mast at least a foot or so into the ground to help anchor the system. A few cement blocks arranged around the bottom of the pole are good for support. Lift the second element into position and attach it to the boom (which is now horizontal) as well. The elements are vertical when the antenna is erected, and one side of the squares or elements lies parallel to the ground. If all this sounds confusing, the pictures will make it crystal clear!

It's a good idea to use guy wire to help secure the antenna; for example, place a guy ring about 10



feet up on the mast. Then hook four guy wires to it and stretch each to an opposite side. These wires can be anchored by tying them to eyehooks screwed into 2x4 inch wooden stakes which have been hammered into the ground. It's also helpful to use lightweight nonmetallic material (such as a high-test fishing line) to connect the spreaders of one element to the spreaders of the other for added rigidity. This time proven arrangement can withstand 60 m.p.h. winds with no damage!

Since it's not easy to move the antenna once the guy wires have been anchored into the ground, you should first decide which direction to point the antenna. For example, consult Planet Finder to determine the position of Jupiter. Remember that whenever Jupiter or the sun is within a few degrees of 40 degrees elevation, they will be within range of the main lobe of the antenna. So determine the optimum direction, and aim the boom axis of the antenna that way. You can then anchor the system in place, and you won't have to alter its position for a couple of months.

A relaying cable must be attached to the antenna so that the signal can be transferred to the receiver, which is comfortably located indoors. *Coaxial cable*, which is a stranded wire with a protective metal sheath and an outer coating made of rubber, will serve this purpose. There are many different kinds of coaxial cable, most of which are

Upper left: You can build a shortwave radio receiver from a kit, and then tune in radio astronomy as well as ham radio. The kits include everything but a few basic tools. **Lower left:** A cubical quad antenna can be built of lightweight wood and bamboo. Here the bamboo spreaders are attached to the plywood center plate with U bolts. **Right:** The completed antenna can be placed in the backyard. Note the coaxial cable that carries the signal into the house at left. Photographs by T.G. Meloy Jr.

available at a local electronics shop. In making your selection, it's necessary to match the *impedance* of different parts of the system. Impedance matching involves making sure that all parts of the telescope which feed into one another are at the same resistance. This is particularly crucial when transmitting signals, for a mismatch will mean loss of power. In the same way, a mismatched system impairs the receiving capabilities. Fortunately, the strong signals sent by Jupiter and the sun save excess worry over this problem. It is sufficient to use coaxial cable #RG59/U-72 ohm. Solder the inner wire directly to the bottom side of the copper wire in one of the elements. This element is then the driven element which must face the desired direction. The other is then the parasitic element, and is behind it. The metal sheath need not be connected at all at the antenna end. Since the antenna has a total resistance close to 75 ohms, the mismatch is not critical. The coaxial cable must be cut into a length which is a multiple of 1/4 wavelength, or you'll have another mismatch. The coaxial cable

may be $1/2$, $3/4$, 1 , $5/4$, $3/2$, $7/4$, 2 — any number of quarter waves. The other end of the inner coaxial cable can then be attached to the antenna connector on the back end of the receiver. The outer metal sheath attaches to the ground on the back end of the receiver. The total cost of the antenna system should be less than \$25.

Receiver

Now consider the receiver for your radio telescope: A standard shortwave radio receiver is all you need! These tend to be expensive, so if you don't have access to one, build one! This is part of the fun of making the telescope, and will save considerable money. Companies such as Heathkit and Knightkit (their "Star Roamer" five band receiver is ideal) sell superheterodyne kits for as little as \$50. A novice can construct a "superhet" receiver in about 30 hours, which is less time than it takes to grind and polish a six inch mirror for a reflecting telescope. Complete easy-to-follow instructions come with the kits, and all that's required in addition are a soldering iron, wire cutters and a screwdriver.

How does a superheterodyne receiver operate? The decametric signal received by the antenna travels to the receiver via the coaxial cable. Within the receiver, the input signal goes to an amplifier. This amplified signal then goes to a *mixer*, where it beats against a strong signal from a *local oscillator*. The resulting output signal has a frequency corresponding to either the sum or the difference of the input and local oscillator frequencies. This *intermediate frequency* signal is again amplified, and sent into a *square law detector*, which changes the incoming signal — alternating current (AC) — to a direct current (DC) signal. The output voltage is proportional to the square of the amplitude of the original input voltage. A *bandpass filter* then selects the frequencies you want. Although it sounds complicated, there's nothing like building one to find out all about it! You listen to the signals when they come through the radio's speaker. For Jupiter and the sun, you'll be listening on band five of the shortwave radio receiver, in the 10 to 30 MHz range.

There are many ways to record the signals received besides just listening. One way is to use a cassette tape recorder to make a permanent record of the entire event. Another is to attach a voltmeter to the receiver to measure the intensity of the signals. A more expensive and sophisticated method is to attach a chart recorder (available from places like Rustrak Recorders for about \$100) to the receiver and keep a permanent record of the bursts. Whichever alternative is best depends on the main objective of your observations. If you just want to hear the bursts, your ear or a tape recorder are sufficient. If you want to try to analyze the structure and intensity of the bursts, a voltmeter or chart recorder may be the best method.

To make voltmeter readings or chart records, an integrating or "smoothing" circuit should be

built into the receiver to help eliminate noise and make monitoring of the signals easier. The circuit will allow the signal to build up and discharge continuously. Noisy fluctuations are smoothed out and allow you to read the average power. The integrating circuit is connected to the primary winding of the audio output transformer of the receiver, where there is an AC signal. The integrating circuit changes the signal into an averaged DC signal so that you can measure its strength.

The time required for the signal to build up is determined by the circuit components. This "time constant" can be calculated with the following formula: time (seconds) = resistance (ohms) x capacitance (farads). If the time constant is too long, the signals will all be smoothed together; the signal will sound like a humming noise, meaning that information about the structure of the bursts has been blurred out. A time constant of a few seconds is probably the best to use. A 10,000 ohm resistor in series with a 1,000 microfarad capacitor, for example, will give a time constant of 10 seconds. The sensitivity meter on the front of the radio receiver (which is a needle indicating signal strength) should register about a 10 percent deflection for the background sky noise with this setup. To build the circuit, attach a 0.1 or 1 microfarad decoupling capacitor to the primary winding of the audio output transformer. Connect a silicon diode to this capacitor, and then attach the resistor and capacitor in series to it. A voltmeter or chart recorder can then be attached in parallel with this second capacitor.

If you use a voltmeter, you'll need to record the signal strength by hand. Take readings periodically — for example, twice during each time constant, or about once every five seconds. This can be a tedious process, but you will learn something about the intensity of the signals you receive.

Things to Do

When the radio telescope is completed and erected, observing can begin! The signals which we receive from the sun and Jupiter are known as "noise storms" or "bursts" because of their sporadic and rapidly fluctuating behavior. The signals are not continuous and the frequencies at which they are produced are not constants. The frequency may change on timescales of a few hours or less, and may drift to higher or lower frequencies even as you listen. The signals are characterized by a buildup and then tapering off of intensity, much like the sound of surf breaking on an ocean beach. For Jupiter, the surflike noise typically takes a few seconds to build up and decline, with individual components of the burst lasting perhaps a fraction of a second. You can be fairly certain that you are listening to Jupiter or the sun if you hear this characteristic type of noise only while these objects are in the main lobe of your radio telescope. These bursts can be heard even if there is interference from local broadcasts.

To Learn More ...

... we suggest that you consult some of the books in this list.

Basic Radio Books (try your local radio or electronics shop)

Goodman, B., *The Radio Amateur's Handbook*, American Radio Relay League (1965) — everything you've ever wanted to know about radio!

Orr, Wm., *Cubical Quad Antennas*, Radio Publications, Inc. (1959) — for details on properly balancing your antenna and line.

Basic Radio Astronomy Books

Hey, J.S., *The Evolution of Radio Astronomy*, Science History Publications (1973).

Heywood, John, *Radio Astronomy and How To Build Your Own Radio Telescope*, Arc Books, Inc. (1964) — nicely reviews the types of antennas you can build at home.

Smith, A. and Carr, T., *Radio Exploration of the Planetary System*, D. Van Nostrand Co., Inc. (1964) — a very readable, introductory summary.

Advanced Radio Astronomy Books (check your university or college library for these)

Gherels, T., *Jupiter*, The University of Arizona Press (1976).

Ter Haar, D., *Solar Noise Storms*, Pergamon Press, Inc. (1977).

Vershuur, G. and Kellermann, K., *Galactic and Extra-Galactic Radio Astronomy*, Springer-Verlag, Inc. (1974).

Solar noise bursts appear to be related to solar flares, those dynamical outbursts on the surface of the sun in which gas is ejected at tremendous velocities. Some bursts occur just at decametric wavelengths, while others cover a wide range of wavelengths which may include the decameter regime. These events may last for milliseconds or minutes.

On Jupiter, the mechanism producing the decametric emissions is not at all well understood. There appears to be a correlation between the position of one of the inner satellites, Io, and the probability of occurrence of the bursts. This may be a result of some type of interaction between the satellite and the planet's magnetic field. There may also be some connection between the rotation of Jupiter and the noise storms. All longitudes on Jupiter rotate at slightly different rates, but for convenience they're broken up into two regions: System I (consisting of the equatorial regions) and System II (consisting of longitudes near the poles). System I rotates in about 9 hours 50 minutes, while System II rotates in about 9 hours 55 minutes. It turns out

that there is some regularity in the recurrence of the decametric noise storms from Jupiter, with a period slightly longer than that of System II. This "radio rotation rate" has been designated System III.

There are many possibilities for your own investigations. For example, try listening to the signals from Jupiter over the 10 to 25 MHz range whenever Jupiter is within the main lobe. It might be fun to record the time the signals are received, and the frequencies at which they occur.

You may also want to keep a record of the duration of each burst and try to estimate the maximum intensity of each by reading the sensitivity meter on the receiver or the output of a voltmeter, or comparing relative intensities by replaying cassette recordings of the events, or by reading the intensities directly from a chart recording which you have made.

It would also be interesting to compare the times of bursts with your own observations of the positions of the Galilean satellites or with ephemeris listings of their positions. You might want to see if you can establish for yourself the correlation between their positions and the receptions of the noise storms.

It's fun to observe the feature markings on Jupiter with an optical telescope at the same time your radio telescope is receiving emissions from the planet.

You can follow this type of procedure for the sun as well. Try listening for bursts, and noting their duration, strength, frequency and time of occurrence. You can keep a sunspot watch yourself and notice the positions and numbers of them. Then look to see if there is a correlation with your radio recordings.

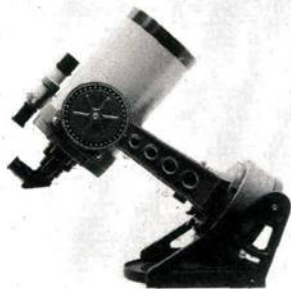
You can also observe over a period of several days when the noise storms from the sun seem to be very strong or frequent, and see if Jupiter's noise storms tend to increase or decrease during that same period. In other words, you can investigate the possibility that solar activity has an influence on Jupiter.

These suggestions may provide the start of a long range investigation of your own invention, or you may have fun just listening to the noise storms. In any case, keep careful records!

Whatever your ultimate goal, the biggest thrill is to turn on the receiver when Jupiter or the sun is within range, and to hear the noise storms for the first time with a radio telescope which you have built! But beware: Jupiter's noise storms can be captivating, and their hypnotic powers may well make a lifetime devotee out of you.

Debra Meloy Elmegreen is currently pursuing a Ph.D in astrophysics at Harvard University. She first became interested in radio astronomy in high school, and used the rig described in this article as a science fair project. It became one of the three top winners of the 1970 International Science Fair, and a Top Ten winner in the Westinghouse Science Talent Search (1971).

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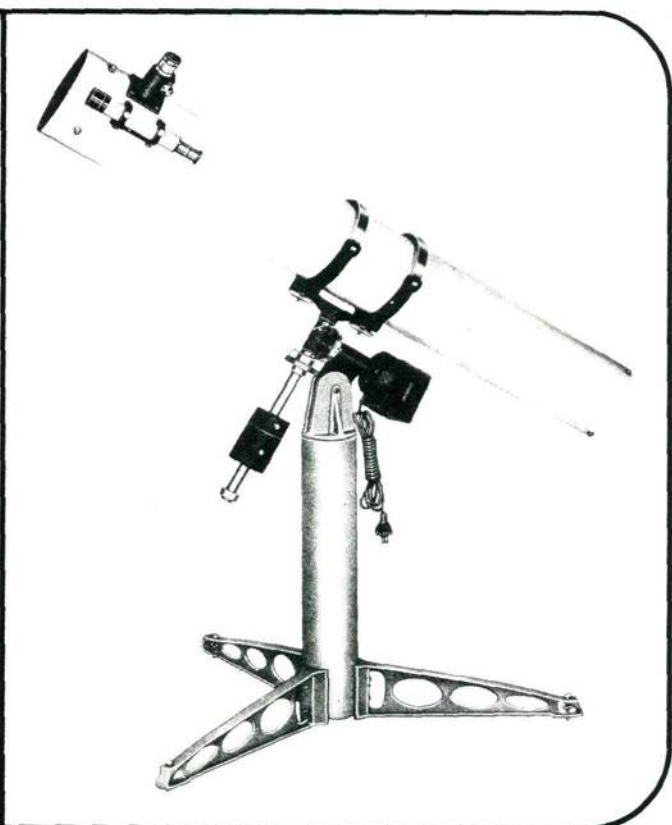
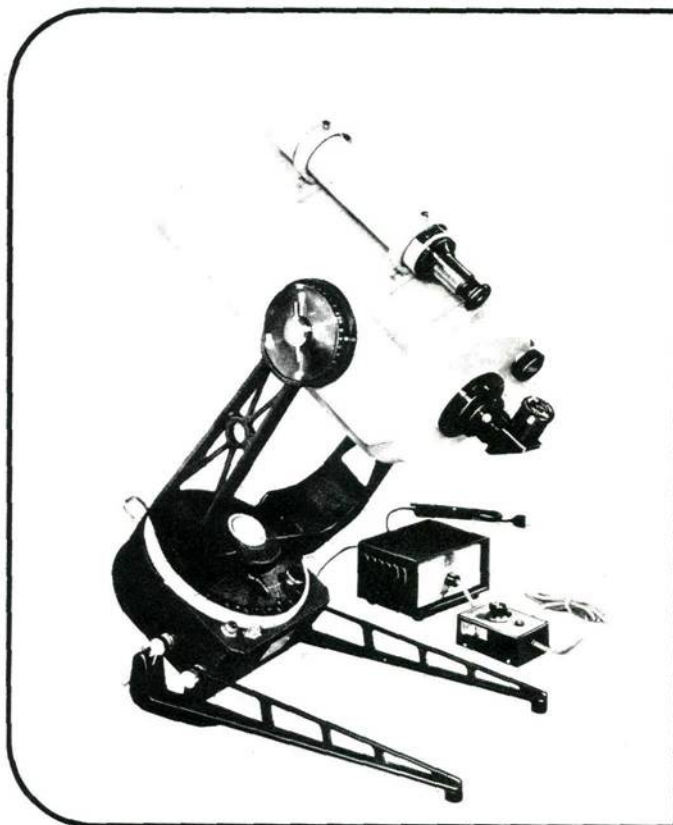
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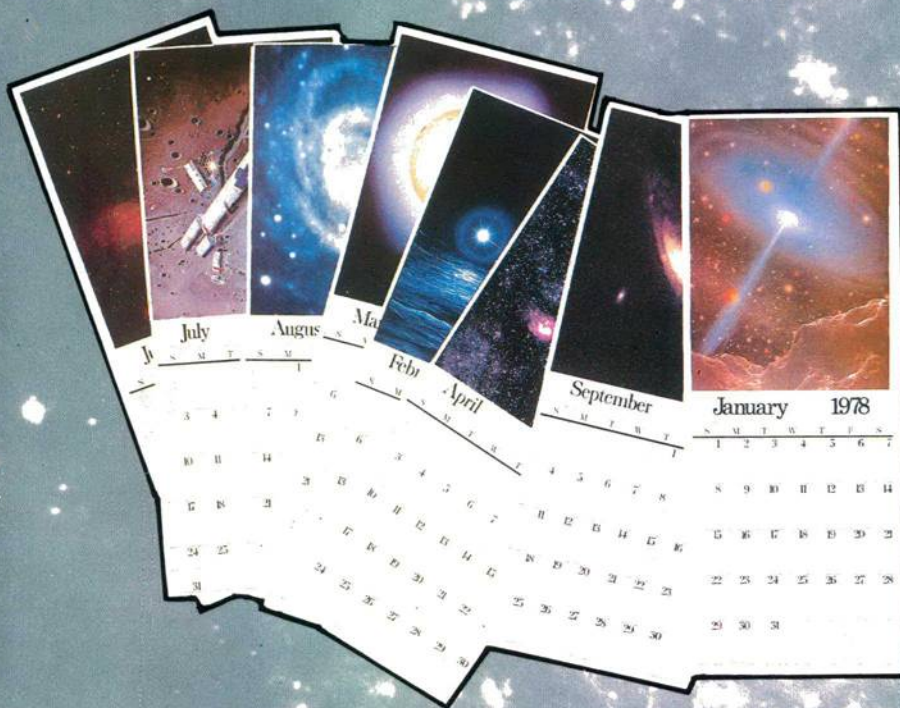
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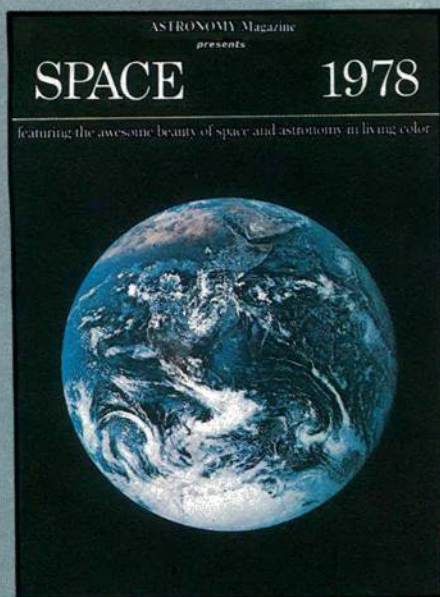
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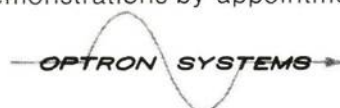
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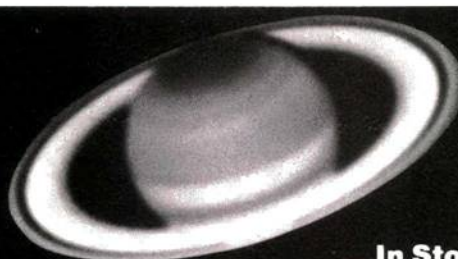
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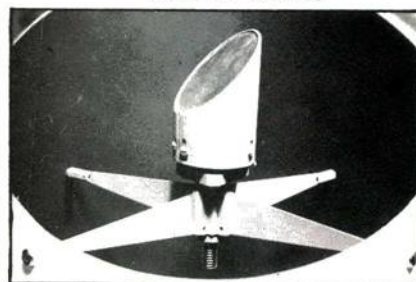
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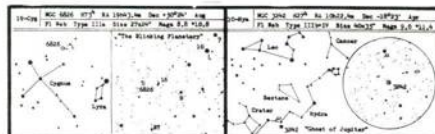
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UK Schmidt Telescope Discovers Supernova

The British Schmidt telescope has just discovered its first supernova, which is located in the distant galaxy NGC-1411. Astronomers Halton Arp of Hale Observatories and Barry Madore of the Institute of Astronomy in Cambridge, England, found the gigantic stellar explosion in mid-July on routine survey photographs. It is in a galaxy 65 million light-years away, and climbed to apparent magnitude 12 at its brightest.

Schmidt telescopes obtain accurate wide field photographs of the heavens. During the last two years, project scientists have used the new British instrument to make a definitive survey of the southern sky that will complement the famous Palomar Sky Survey of the northern sky. They expect to finish the first survey within about a year. A similar program is underway at the European Southern Observatory (ESO) in Chile.

The 48 inch (1.2m) instrument is located on the Siding Spring mountain

in Australia. This is also the home of the Anglo-Australian 153 inch (4m) telescope. These facilities are rejuvenating British optical astronomy, which has been seriously retarded by England's cloudy skies.

Schmidt astronomers typically spend three years in Australia, some 15,000 miles from their home base at the Royal Observatory in Edinburgh. There are facilities for storing, examining, and measuring the plates.

Arp and Madore are currently compiling an immense catalog of southern peculiar galaxies. They've already listed over 35,000 objects, and expect the final listing to run to 120,000 entries.

While scanning a recent batch of plates, they chanced on a curious jet of light emerging from the core of an elliptical galaxy. Ever since the discovery of a jet of light in M-87, a giant elliptical galaxy, astronomers have considered them important signs of violent activity.

On looking more closely, Arp and Madore realized that the jet was an optical illusion. Instead they were actually seeing the diffraction spikes of a brilliant star embedded in the galaxy. Diffraction spikes usually occur when a point source of light is imaged by a telescope.

Inspection of the photograph of the same galaxy taken a few months earlier by the ESO Schmidt showed nothing remarkable, which immediately suggested that a star had erupted in the intervening months. The two researchers contacted Australia with a request for another photograph of the galaxy. In early July, the vital exposure needed to confirm that the star really existed was obtained; it was an enormous outburst in another galaxy.

The stellar explosion has now faded to magnitude 17. Madore estimated it peaked at magnitude 12 sometime before his discovery. At this level, it equalled the luminous output of the rest of its parent galaxy, a family of billions of stars.

No supernova has been sighted in the Milky Way since the invention of the telescope, but they must surely have occurred, hidden from us by great clouds of interstellar dust. Statistical arguments suggest that a visible one is long overdue. While waiting for it, astronomers must survey these unpredictable displays. Supernovae signal the death of massive stars about 3 to 20 times as large as our sun, and perhaps the birth of a new pulsar. The extragalactic supernovae are important indicators of extragalactic distances. And, the measured apparent brightness gives a clue about how far away the parent galaxy is.

Patrols of certain areas of the sky are routinely carried out at Palomar in order to capture northern supernovae; about 15 are found each year in this way. This number will increase when the southern Schmidts are able to join the night patrol. ☛

Saturn's 11th Moon?

Saturn has at least 11 satellites, according to University of Arizona astronomers John Fountain and Stephen Larson. They recently re-examined photographs taken in 1966 with the Lunar and Planetary Laboratory's 61 inch (154cm) Catalina reflector. The rings were then edge-on, and there was consequently less glare around the planet to obscure faint objects.

French astronomer Audouin Dollfus, observing from the Pic du Midi Observatory, discovered Saturn's 10th satellite, Janus, in 1966. Fountain and Larson have now confirmed the existence of Janus (which some astronomers have doubted), and also found evidence on the photographs of at least one other satellite.

They combined the LPL observations with those made by Jean Texereau at

McDonald Observatory in Texas, by Richard L. Walker Jr. at the U.S. Naval Observatory's Flagstaff station, and Dollfus, to confirm the new satellite's existence and calculate its orbit. Fountain and Larson determined that it orbits Saturn every 16.65 hours at a distance of 90,780 miles (151,300km) — meaning that it is nearer than Janus; its estimated diameter is 120 to 300 miles (200 to 500km).

Janus and this proposed 11th satellite may be the largest bodies of an outer, so-called E ring, of Saturn. Further observations will be possible in 1979 and 1980 when the rings are again seen edge-on. The Voyager 1 probe will also be photographing Saturn in late 1980, when its cameras should confirm the existence of any such large bodies at the edge of the rings.

Kennedy Space Center Reshaped In Preparation for Space Shuttle

It has been nearly two years since launch complex 39 at NASA's Kennedy Space Center (KSC) last reverberated from a rocket catapulting men into space. And it will be nearly two years more before the Space Shuttle makes its first orbital flight.

Many of its sprawling and massive facilities — built for Apollo journeys to the moon — have already been reshaped for their new roles in the Space Shuttle era.

KSC was selected in 1972 as the primary launch and landing site for the Space Shuttle. Construction has been aimed at preparing to receive the first shuttle flight hardware in 1978 and to support the first manned orbital flight in 1979.

Among factors leading to KSC's designation as the prime shuttle site was the existence of complex 39, with structures readily adaptable to shuttle launch and servicing requirements. To keep costs down, planners were directed to utilize existing buildings that could be modified. New facilities were to be built only when a unique requirement existed.

The Space Shuttle is a new breed of machine which will be launched like a rocket, will maneuver like a spacecraft and land like an airplane.

KSC's existing physical plant was so adaptable that only two major new facilities were required.

One was the *orbiter landing facility*, on which the shuttle orbiter will land on its return to Earth. This concrete runway, one of the largest in the world, is located northwest of the vehicle assembly building and is roughly twice as long and twice as wide as the average commercial landing strip. It is 1,500 feet (4.5 kilometers) long, 300 feet (91 meters) wide and has a 1,000 foot (300 meter) safety overrun at each end. Its equipment includes a *microwave scanning beam landing system* which will guide the orbiter to an automatic landing on its return from a mission in space.

The second is the *orbiter processing facility* (OPF), which is located in the heart of complex 39 and connected with the landing facility by a two mile (3.2 kilometer) towway. The OPF is essentially an aircraft hangar with two high bays in which orbiters will be checked out and serviced immediately after landing. Protected from the elements, ordnance and residual fuels

will be rendered safe, flight and landing systems refurbished, and payloads removed and installed.

A technological "facelift" has been undertaken to prepare existing facilities for new roles. The *vehicle assembly building*, site of assembly for the Saturn V/IB rockets used in the Apollo, Skylab and Apollo/Soyuz programs, is being modified for assembly of the Space Shuttle in two of its four high bays. The remaining two high bays will be used for processing and staging the shuttle's solid rocket boosters and external tank.

The *launch control center* (LCC), "brain" of the complex, is being fitted out with the highly automated *launch processing system* (LPS) developed for shuttle checkout and launch. Two of the LCC's four firing rooms are being equipped with LPS consoles and associated equipment. The new system is so sophisticated that only about 1/10 the manpower required for Apollo will be needed in the firing room to check out and launch the Space Shuttle — 45

Kennedy continued on page 67



An Apollo/Saturn mobile launcher is being renovated for use as a Space Shuttle mobile launcher. The umbilical tower was removed, and the single "flame bucket" was replaced by the three flame buckets required by the Shuttle Orbiter. NASA photograph.



Complex 39's pad A, a veteran of many Apollo launchings, has begun to take on a new shape in preparation for the Shuttle launchings. The shorter of the two pad structures is the new payload changeout room, and the taller pad structure is an old Apollo/Saturn mobile launcher being used for fit checks. NASA photograph.

Kennedy *continued from page 66*

persons as compared to more than 450! And the final countdown for the Space Shuttle is expected to take only 2-1/2 hours as compared to the 28 hours needed for the final countdown for an Apollo/Saturn V.

Launch pads 39-A and B are undergoing major changes. With the exception of the six fixed pedestals which support the *mobile launcher platform*, the structures on the surfaces of these twin pads originally built for Saturn launches will be removed or relocated.

The upper portions of the umbilical towers from the mobile launcher platforms are being removed and installed at each pad to serve as fixed shuttle service and access towers. With the exception of Spacelab — a large space laboratory being built by the European Space Agency — payloads may be loaded into the shuttle orbiter at the launch pad from the payload changeout room.

The *payload changeout room* (PCR) is a "white room" structure mounted on a semicircular track extending from the shuttle service and access tower. The PCR is "swung" along its track to its park position prior to launch.

The *Saturn mobile launchers* are undergoing major changes to adapt them for the Space Shuttle. The most striking visual changes involve removal of the launch towers and their cranes from the platform. The need for these have been eliminated on the mobile launcher platforms by installation of permanent launch towers on the pads.

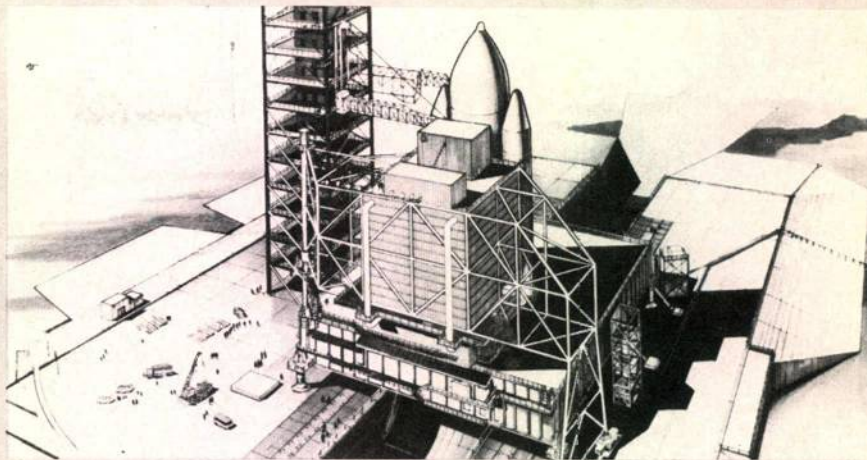
The single opening in the center of the mobile launcher platform is being replaced by three openings to permit exhaust gases from the orbiter's main engines and two solid rocket boosters to escape during liftoff.

The ponderous transporters bearing massive loads on a back the size of a baseball diamond will be used to move mobile launcher platforms with the assembled Space Shuttle between the vehicle assembly building and complex 39's two launch pads.

These twin giants were originally adapted from strip mining machinery to carry Saturn V/Apollo flight hardware around complex 39. Both have amassed odometer readings in excess of 500 miles (800 kilometers).

The transporters are expected to remain capable of performing their load-carrying chores throughout the life of the Space Shuttle program.

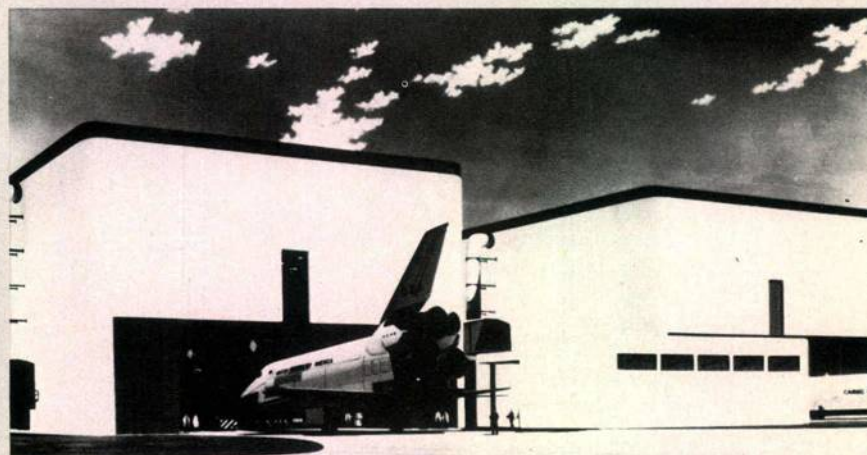
Much of the construction and modification work has already been completed. The eventual cost of the entire project will approximate \$240 million — less than 1/4 the cost of building the Spaceport for Project Apollo in the 1960s. 🐞



This illustration shows the construction features of the payload changeout room (PCR). Payloads can be loaded vertically into the orbiter from the PCR under environmentally sterile conditions. The PCR is mounted on a semicircular track enabling easy access for payload loading, and can be swung on its track until it fits flush with the orbiter. Should a rescue mission be necessary, the payload could be changed in a matter of days. NASA artwork.



The Space Shuttle is shown here as it will look like shortly after launch. The two solid rockets, flanking the larger propellant tank, are jettisoned at approximately 100,000 feet (30,000 meters) altitude. The solid rocket tanks are recovered from the ocean after launch for future use. The large propellant tank is discarded just before insertion into Earth orbit. NASA artwork.



Shown is the spaceship as it enters the orbiter processing facility. The orbiter is given a thorough going-over, the payload and residual fuel are removed, and preparations are made for its next flight. NASA artwork.

Radio Astronomy Observatory Built By Five Massachusetts Colleges

Five Massachusetts colleges have combined their efforts to produce what may be the world's most sensitive millimeter wave radio telescope. Built and operated primarily by the University of Massachusetts, the Five College Radio Astronomy Observatory's (FCRAO) 45 foot (13.5 meter) diameter receiver will allow the best opportunity to study the 1.3 to 13mm wavelength radio "window". This window on the universe requires an extremely smooth surfaced parabolic collector and a highly sophisticated receiving system.

With a parabolic surface accurate to a few thousandths inch, it is really a hybrid of radio and optical telescope design. It's not only an engineering achievement but an accomplishment in frugality. All of the electronic receiving systems were designed and built by UM staff with a savings in construction of over \$4 million. Ninety percent of the funds came from private foundations; additionally, the National Science Foundation contributed \$200,000 for the facility's construction. Much of the construction labor was volunteered by undergraduate students from four private colleges (Smith, Amherst, Mount Holyoke and Hampshire), and the state supported University of Massachusetts.

The first anticipated project will be to aim the fully steerable telescope at Venus to study the upper atmosphere, searching for living organisms. Dr. Richard Huguenin, head of the observatory, said, "We won't be able to listen to the organisms talking to each other, but we may detect the organic waste products of the organisms — if any exist."

Another target for similar pioneering research will be the planet Jupiter. Both planets are thought to have zones in their dense atmospheres that duplicate conditions near Earth's surface, but probably with different compositions and combinations of gases.

A project that should appeal to the more practical-minded is the study of our own ozone layer. This layer of molecules is vital to the shielding of deadly ultraviolet radiation constantly radiating from our sun.

"We'll be able to study the destruction of the ozone layer on a more continuous basis with greater detail than is possible using other techniques. C10, the product of a destroyed ozone molecule, will be our main indicator of just how much ozone is being converted," Huguenin said. In addition to FCRAO funding,

\$60,000 has been donated by NASA and the Society of Manufacturing Chemists for the ozone project.

A detailed study will be made of various interstellar clouds made up of complex molecules. These unexpected clouds, located in the last decade, are forerunners to a long list of molecules, with an increasing complexity, now being found in huge quantities.

It is not yet known if these molecules are floating free or attached to small dust particles in the 10 micron range. When asked if it's possible that life itself could be floating in interstellar space, Huguenin replied affirmatively. Many researchers think such clouds could be a vital contributor to a life sustaining atmosphere on newly formed planets.

Inferometry will also be an important part of the work at the FCRAO. The first linkup will be with the famous 120 foot (37 meter) Haystack radio telescope located about 47 miles (75km) to the northeast. The Haystack is not a true millimeter telescope, but if it is tuned to its shortest frequency and the new telescope to its longest frequency, then enough overlapping will occur for accurate results. If this is successful, more distant linkups will be attempted.

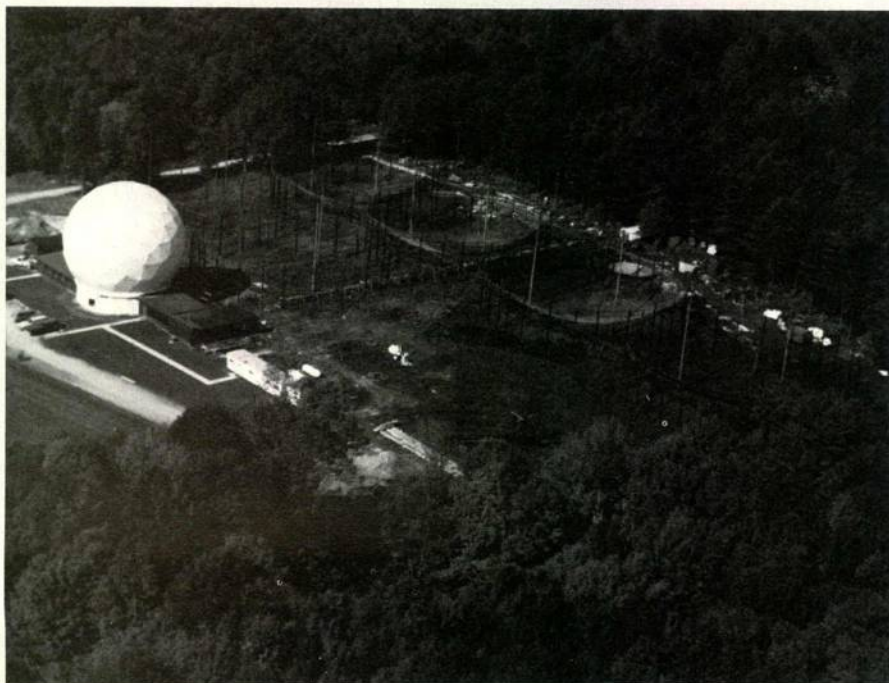
The FCRAO has another unique radio telescope that has been in operation since 1971. It is the only meter wavelength telescope in the world devoted exclusively to the study of pulsars. Hug-

uenin and a colleague were credited with the first American discovery of a pulsar. (Jocelyn Bell discovered the first pulsar while studying with Anthony Hewish in Cambridge, England.)

The radio telescope consists of four 120 foot (37 meter) wire mesh parabolic dishes. The dishes are not steerable, but the instruments mounted at their focus are movable. The four collectors are simultaneously pointed at the same object, and the aiming is done automatically along with the data collecting and recording. Over one million bits of information on the 150 known pulsars are collected each week. Because the instrument operates 24 hours a day, short-term changes in the pulse rate of each pulsar can be readily detected with little chance of it going unnoticed.

Future plans for the FCRAO call for construction of an infrared telescope and four more 120 foot collectors for the study of pulsars. The four existing ones equal the 250 foot (75 meter) Jodrell Bank instrument in England in terms of usable aperture. These collectors require no expensive protective dome, and were made of surplus steel cables, fence wire and telephone poles.

The 20 acre observatory grounds are surrounded by 1,000 square miles of wilderness which is closed to the public to insure a clean water supply for Boston. Consequently, the astronomers are assured of a minimum of radio noise. 



MANAGING EDITOR'S MEMO

Things are slowly beginning to calm down and return to their usual "abnormal" state at ASTRONOMY.

During the last several weeks, we've given a lot of thought to the tasks and titles of each person on our staff, and have reached a few decisions we'd like to share with you.

First, we've decided to eliminate the title of editorial director since our entire editorial staff actually provides input in that area. And, we've promoted **Richard Berry** to Editor . . .



Richard will be responsible for selection of all the articles, paintings and photographs appearing in ASTRONOMY each month. He'll make assignments to both our contributors and staff, working closely with them to provide you with the best possible magazine every month.

Richard will plan the content of future magazines, hold editorial staff meetings and critiques on newly published issues, work on special projects (which we'll surprise you with later), sweat over trying to meet our editorial department budget, and review materials submitted by our readers. And as if that isn't enough, he'll continue to write and edit articles for the magazine.

Moving to another area, we've got a newcomer (of sorts) on our staff. As our circulation has continued to grow, we've had many more orders to fill for posters, etc. So we decided to hire **Bruce Precourt**



. . . as our Mail Room Supervisor. (He's been with us part time in the mail room since November 1976.) Incidentally, Bruce has been interested in astronomy for as long as he can remember, and has occasionally contributed diagrams to ASTRONOMY.

Bruce will fill all of your orders for posters, calendars, back issues, indexes, etc., and will generate reports for our circulation department. He'll also handle bulk shipments of ASTRONOMY to planetariums, maintain inventory records, and will occasionally pinch hit at the typewriter or switchboard!

Since early this summer, Henry Phillips has been writing a short daily column ("Eye on the Sky" — a mini-mini-Sky Almanac) for the *Milwaukee Sentinel*, our morning newspaper. *Sentinel* editors have told us the column has been very well received and is gaining in popularity. We're hoping to syndicate "Eye on the Sky" within the next few months, and would be quite interested in how many of you, our readers, would like to see it in your local papers.

Well, that's about all the news we have for now . . . except that I'm in what seems like a 50 pound cast after breaking my foot two days ago. If any of you have any pointers on how to stay on your feet with crutches, I'd sure welcome them!

Penny Oldenburger

Penny Oldenburger
Managing Editor

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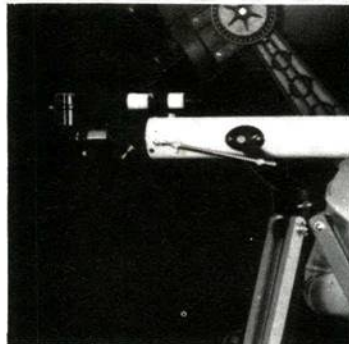
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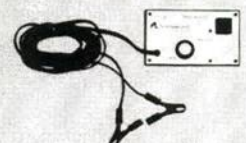
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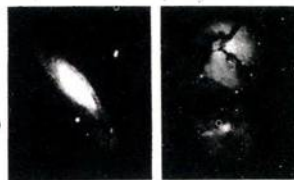
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STAR DOME

DECEMBER

by

James Mullaney and Henry J. Phillips

Many bright stars and constellations are making their annual reappearance in the evening sky during December — and they're putting a little excitement back into stargazing! While no one can deny the attractions of many objects that are best seen during the autumn (including those featured in our Close-Up sections during the last three months), there's a certain placidity — some might go so far as to say dullness — in the fall sky compared to winter's embarrassment of riches. Just compare the "wastelands" of groups like Pisces, Cetus, Sculptor and Fornax with the crowded conditions along the winter Milky Way, and you'll know what we're talking about.

It probably seems strange, therefore, to turn to this month's Close-Up section and discover that our featured region is Camelopardalis — because if ever a celestial desert existed, it's here. Unless your sky is absolutely clear and free from light pollution, the chances are good that when you look up into this area you'll see perhaps two or three fairly dim stars — or worse, nothing at all!

So why bother talking about Camelopardalis when we could look at Orion, Taurus, Auriga, or one of the other bright constellations now climbing high in the east? Well, there are several reasons. The most obvious is that the Camelopardalis region is in the sky and, by virtue of that alone, merits a certain amount of attention. Our Close-Up sections are designed to

include every part of the celestial sphere over a period of several years, and constellations like Camelopardalis — which don't contain very many bright stars — are nevertheless part of the sky and must be included in any survey of the heavens that purports to be complete.

But there's more to it than that. We could have decided to feature only the brightest and most interesting constellations in Close-Up, leaving areas like Camelopardalis for readers to pick up on their own. Unhappily, too many observers' guides to the sky — including several classic works that we often refer to in Star Dome — do exactly this, giving exclusive attention to the "best" groups (like Orion) and ignoring the others. The result is that the casual observer who does eventually want to learn about Camelopardalis can't find information about it anywhere!

In addition, the dimmer star groups often contain several interesting doubles or deep sky objects that are certainly worth a look or two through your telescope. If observers don't know about them, however, they certainly can't be expected to find them, and therefore frequently neglect some of the sky's most attractive sights. How many of you have never seen M-27, the Dumbbell nebula, because it's situated in the otherwise dull constellation Vulpecula, which is all too often passed over by observers' guides? (Also see our comments below on the galaxy NGC-2403.)

All this is said not to pretend that Camelopardalis is a prominent constellation; it isn't, and never will be considered so. But somehow it doesn't seem quite fair to spend all your telescope time on the bright and easy stars and constellations, while forgetting about the dimmer ones. If nothing else, you can build up your observing skills a lot more efficiently by attempting to locate objects that aren't as simple to find and see as, for example, the Orion nebula.

Camelopardalis is not one of the ancient constellations (most of the very dim ones aren't), but is a 17th century "invention". Most reference books attribute its formation to Jakob Bartsch (usually known by the "Latinized" form of his name, Bartschius), who included Camelopardalis in his 1624 atlas, *Planisphaerium Stellatum*. Others disagree about its actual inventor; in any case, it was Bartschius who wrote that, to him, the group represented the camel that brought Rebecca to Isaac — a story related in the Biblical book of Genesis. By this, Bartschius inadvertently let slip his own confusion as to the identity of the animal, for the word "Camelopardalis" means, not a camel, but a giraffe! In ancient Roman times, the giraffe was described as an animal with the hump of a camel and the spots of a leopard; a combination of the two animals' names gives us "camel-leopard", or camelopard.

This Star Dome rendering approximates the sky as it appears at about 10:30 p.m. Local Standard Time early in the month. The same constellations are visible one hour earlier during the latter half of the month. To use this constellation finder, hold it overhead so the compass points line up with North, South, East and West in your backyard or viewing area. For example, to find constellations in the southern part of the sky hold the chart in front of you so the South compass point faces the southern horizon. Repeat this procedure for East, West and North. Since only the brighter stars are represented in this map, you should be able to trace out the geometrical shapes of the constellations with ease. To find planets, asteroids, etc., visible among the current month's zodiacal constellations, refer to the planet finder on page 28.

EAST

NORTH



Map Centered on 40° North Latitude

SOUTH



Map by Adolf Schaller

There are no mythological stories involving giraffes that might be connected with Camelopardalis; we can only assume that the constellation's inventor was merely trying to introduce to the sky what must have been — to him — a very exotic animal. No nation or people of antiquity ever attributed any character or object into the dim stars of this region — except the Chinese, who placed seven groupings inside its borders, including one called “Unostentatious Virtue”!

You'll notice, when you look at a map of Camelopardalis, that very few of its stars have Greek letter designations, but that quite a few are numbered. In our discussion of the Greek alphabet (see *Star Dome*, September 1977), we made a passing reference to “Flamsteed numbers” — a system of star designation that we'll expand on here.

John Flamsteed, England's first Astronomer Royal, prepared near the end of his life what was meant to be the most complete atlas yet of the sky; it was published posthumously in 1729 as *Historia Coelestis Britannica* (or “British Atlas of the Heavens”). Flamsteed departed from the convention, begun by Johann Bayer in 1603, of giving the stars Greek letters in order of brightness; instead, he numbered the stars in a constellation in order of right ascension, moving from west to east without reference at all to the stars' luminosity. Therefore, almost all stars that have a Greek letter also have a Flamsteed number — but not all stars that bear Flamsteed numbers have Greek letters. Since there are only 24 letters in the Greek alphabet, even the richest constellations could only have 24 Greek-lettered stars (unless the convention is circumvented by calling stars Theta 1, Theta 2, etc.). But a constellation can have any number of stars with Flamsteed designations; the champion in this category is Taurus, whose Flamsteed numbers go all the way up to 141!

Unfortunately, there doesn't seem to be much “rhyme or reason” to Flamsteed numbers. It seems that Flamsteed (or the assistants who completed his work after he died) wasn't very careful about assigning a limiting magnitude, below which numbers were not assigned. As a result, some constellations contain stars without Flamsteed numbers that are brighter than some of those bearing them. Also, we have cases like Aries and Auriga: Both contain 66 Flamsteed numbers, but most of those in Aries are quite dim, and many stars in Auriga that are just as bright do without. This is in spite of the fact that Aries is fairly small, while Auriga is much larger, is situated directly on the Milky Way, and contains a great many more stars.

Furthermore, the constellation boundaries weren't standardized in Flamsteed's day, and would not be until about two centuries after his death. When the official boundaries were drawn, the stars that Flamsteed had numbered in one constellation were sometimes placed across the border in another.

Camelopardalis provides a good example of some of these problems. A few of the constellation's brightest stars near its western boundary have no number at all — and the stars labeled 45, 46, 48, 52 and 54 Camelopardalis are now located in Lynx, while 55, 56 and 57 are in Ursa Major!

Despite these drawbacks, Flamsteed numbers are handy for large constellations in which only a limited number of stars bear Greek letters. Last month's Close-Up region, Pisces, included several interesting stars that are identified by their Flamsteed numbers, in addition to those with Greek letters. Camelopardalis, having virtually no Greek-lettered stars at all, needs its numbers even more.

One final note of interest about Camelopardalis: Of all the constellations that date from the 17th century or later (the so-called “modern” constellations), Camelopardalis is the largest. With an area of almost 757 square degrees, Camelopardalis stands 18th in size among all the recognized star groups, and outranks all its companions of the modern era! Such facts may provide that little added impetus to take a look at this constellation, one of the sky's faintest groups.

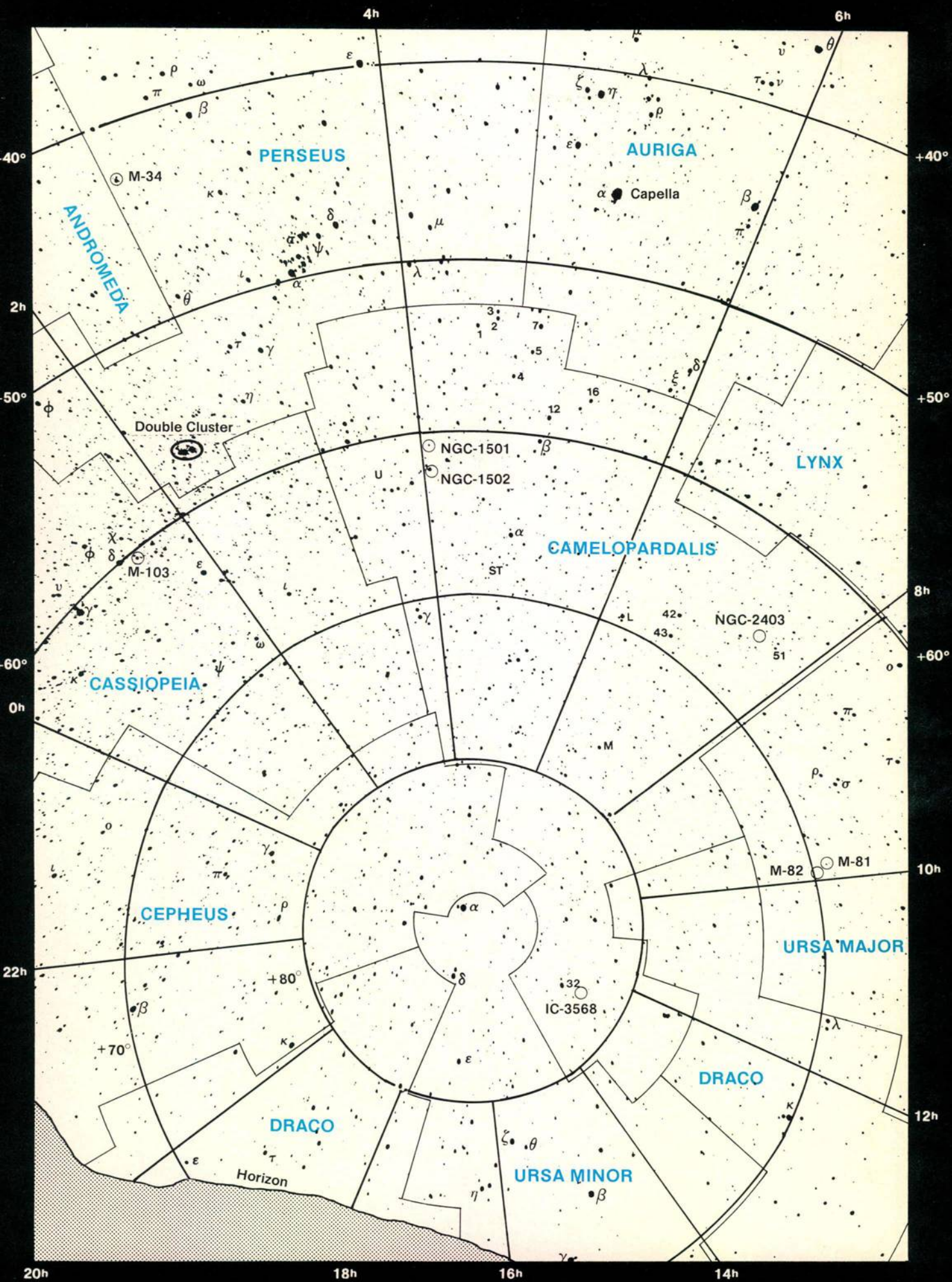
Close-Up

Camelopardalis Region

Camelopardalis is a large, dim constellation having no luminary brighter than fourth magnitude; it lies near the north celestial pole between Ursa Major and Cassiopeia. Even its name is confusing, for we're led to expect a camel residing here, when the figure is actually supposed to represent a giraffe! The former would seem more appropriate anyway, in view of the lack of prominent stellar landmarks in this region — a real celestial desert.

Some authorities still prefer the older spelling of this constellation's name (Camelopardus) to that given here, and you're apt to find either version on star charts and lists. Barns considered the “most inviting portion of this mammoth constellation” to be its western sector, near its boundaries with Perseus and Cassiopeia. In particular, he said, “In the area between





Photograph by Brad Wallis and Robert Provin / Map by Henry J. Phillips

declination 50 and 60 degrees will be found many dazzling gems." Indeed, hundreds of faint double and multiple stars are sprinkled throughout the Camelopardalis region — mostly objects from the Struve catalogs.

The apparent emptiness of this somber area can be sensed in another of Barns' remarks — this one concerning its brightest star Beta (β) Camelopardalis. He described it as "A

monarch in lone splendor". Yet another indication is the complete omission of this constellation by a number of prominent observers, including Olcott, in their classic works!

The most balanced assessment of this month's region is that given by Webb, who described it as "wide-spread, but obscure; containing many good telescopic objects". We've encountered this in Star Dome many times before — sky areas that look dull to the unaided eye but contain telescopic treasures in abundance. Camelopardalis is no exception, as our table of selected objects shows. You'll need to search and identify carefully to find your way here, but the many wonders to be seen are well worth the effort.

Incidentally, it's worth noting that our photo and map (pages 76 and 77) both show a view of Camelopardalis as you'd see it looking north — the direction you're likely to be facing when you observe it. Some areas of the map may appear "upside-down" in this orientation, but remember your directions and it'll be clear.

U and ST Camelopardalis

We begin our telescopic survey of this month's region by examining two superb rubylike gems. Both are semiregular variable stars of the deep red spectral class N5.

One of these is U Camelopardalis, situated just three degrees due west of

the open cluster NGC-1502. Its light varies from visual magnitude 7.7 to 8.7 in a period of roughly 400 days.

The other star is ST Camelopardalis, found about two degrees north and slightly west of Alpha (α) Camelopardalis. Its range is 6.9 to 8.3 magnitude, but no certain period for its variation has been discovered.

Both objects are stunning sights in three and four inch telescopes over their entire ranges, and larger apertures enhance the view even more. This is not only because the increased light grasp intensifies the tints, but also because more background stars become visible, resulting in a greater "depth effect" — the vivid impression that these lovely pulsating beacons are indeed suspended in the void of space!

U and ST are sure to delight you on a dark night, and at the same time encourage further exploration of this little known but rewarding region.

32 Camelopardalis

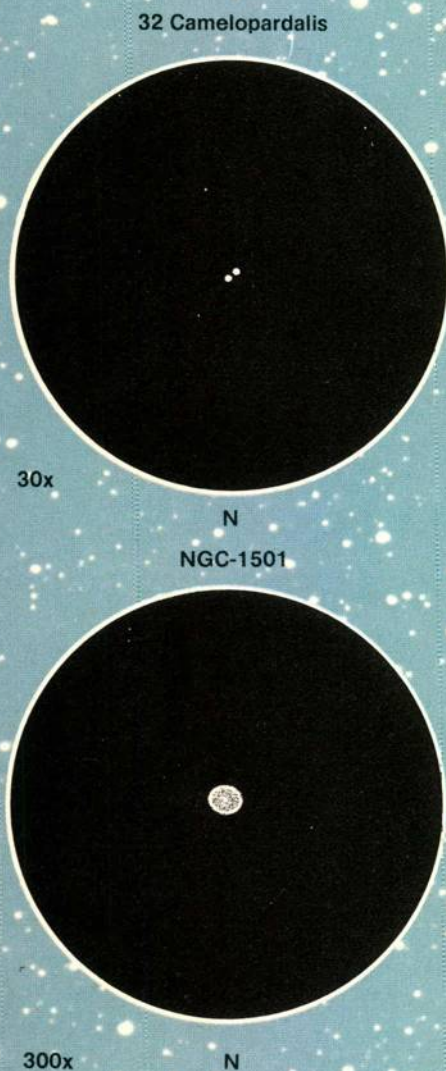
From a pair of unattached single stars, we journey next to a duo of physically bound suns drifting through space together. This is the double star 32 Camelopardalis, brightest and best of this region's host of stellar combinations. Look for it along a line from Mizar (in the Big Dipper's handle) to Polaris the pole star in Ursa Minor; 32 is located about seven degrees from the latter. Shining at magnitude 4.8, it's easily visible to the unaided eye in an area all to itself.

For some strange reason, this object is better known by its designation in the Struve double star catalog than by its Flamsteed number. Indeed, most star charts and deep sky lists refer to the pair as Struve 1694 instead of 32 Camelopardalis. (The usual rule in star nomenclature is that the proper name, Greek letter or Flamsteed number takes priority over special catalog designations, unless the object has none of the three assigned to it.)

The components here are roughly matched at magnitudes 5.3 and 5.8, and are an easy 22 seconds of arc apart. The fainter star lies near position angle 325 degrees (northwest) with respect to the brighter one. Although there has been little sign of orbital motion to date, the two suns are moving across the sky together as a common proper motion pair, and are therefore gravitationally bound to each other.

Even a two inch telescope at 30 power gives a pleasing view of 32 Camelopardalis, as our drawing indicates. Indeed, magnifications much in excess of 50 diameters tend to spoil the scene by unduly separating the components.

Most observers see the primary star as pale yellow in tint and the



Top: 32 Camelopardalis is an attractive double star in the northernmost section of the constellation, near the north celestial pole. Its nearly equally bright components are bright white, although some observers have seen subtle traces of color. This drawing shows the view through a two inch refractor at 30 power; the field of view is about 1-1/2 degrees. **Bottom:** NGC-1501 is a difficult planetary nebula, best seen through fairly large instruments. The visual impression is that of a closed ring, as shown in our drawing made from an eight inch reflector at 300 power. The field of view is about 10 minutes of arc. Drawings by James Mullaney.

Selected Objects — Camelopardalis Region

Object	Type	Mag.	Size/Sep.	R.A. (1950)	Dec.
* U Camelopardalis	V:400	7.7-8.7	—	03 ^h 38 ^m	+62°29'
* NGC-1502	OC	5.3	7'	04 ^h 03 ^m	+62°11'
* NGC-1501	PN	13	56"x48"	04 ^h 03 ^m	+60°47'
1 Camelopardalis	★2	5.9,6.9	10"	04 ^h 28 ^m	+53°48'
* ST Camelopardalis	V:?	6.9-8.3	—	04 ^h 46 ^m	+68°05'
* NGC-2403	Sp	8.9	17"x10'	07 ^h 32 ^m	+65°43'
IC-3568	PN	11.6	18"	12 ^h 32 ^m	+82°51'
* 32 Camelopardalis	★2	5.3,5.8	22"	12 ^h 49 ^m	+83°41'

* Detailed in Close-Up

★2 = Double Star
V:#d = Variable Star, period
PN = Planetary Nebula
OC = Open Cluster

Sp = Spiral Galaxy
Mag. = Magnitude
Sep. = Separation

companion bluish or lilac. Others agree with Smyth in making both members of this system bright white in cast. In any case, the color contrast is not obvious and requires some skill to pin down. What heavenly shades do you see here with your telescope?

At least one observer of the past saw both components of 32 Camelopardalis as equal in luster, and they may well be more nearly matched than the magnitude figures above indicate. Webb's description of this object also suggests this possibility: "Some difference 1852, 3.7 inch (refractor): pale yellow? pale violet? not quite a match, 1863, 5.5 inch (refractor)." Could it be that one of the stars is variable in brightness? Considering the neglected state of the Camelopardalis region, this would not be a surprising discovery!

Both suns are of spectral type A, and there is an unseen spectroscopic member circling the fainter star in a period of 3.3 days. Together the system lies more than 300 light-years from us.

NGC-1501

Our next offering is a seldom seen planetary nebula: NGC-1501, located due west of Beta Camelopardalis in a naked eye trapezoid of stars. Lurking in the night far beyond the range of finders and even small telescopes, it must be swept for with a fair sized instrument.

Its vital statistics are magnitude 13 and apparent size 56 by 48 seconds. As with most planetaries, the magnitude usually listed is photographic. Visually, NGC-1501 is perhaps a full magnitude brighter since it can be glimpsed in a four inch scope. It is classified as oval in form and has a faint 13th magnitude central star.

This object is also designated H IV-53, being the 53rd discovery in Sir William Herschel's class IV (planetary nebulae). It is considered a difficult object (see "Observing Planetary Nebulae", *ASTRONOMY*, August 1977), and so it is. At least a six inch aperture is needed for a worthwhile view, which barely shows it at 50 power on an average night. At magnifications over 100, such an instrument reveals a round, sharp edged disk which seems to flicker continuously because of atmospheric effects. The scene in an eight inch reflector at 300 power is shown in our drawing, which suggests the presence of a nucleus.

Webb described NGC-1501 as "small and dim" but did not indicate which of his telescopes was used for the commentary. He added that Lord Rosse "sees it a bright ring, with star (14th magnitude) in central darkness". This closed ring aspect can be seen even in a six inch reflector at high power. Barns' impression with

his 10 inch reflector was: "Small, curious, with star center."

Observatory photos show this planetary to have a mottled look to it — a fairly uniform distribution of bright and dark condensations across its disk, giving it the appearance of some colossal cosmic sponge riding the ocean of infinity! Its distance is estimated at nearly 14,000 light-years.

NGC-1502

Small telescope users who are disappointed with NGC-1501's showing can find ample compensation nearby in the form of a tiny but striking open star cluster. This is NGC-1502, only 1.5 degrees north of the planetary and its trapezoidal framework. It is number 47 in Herschel's class VII — compressed clusters of small (faint) and large (bright) stars.

NGC-1502 contains about 15 stars that together shine at magnitude 5.3 and occupy an area only seven minutes in extent. It is small for its class and is intermediate-rich in concentration. It can be glimpsed in binoculars and is a fine sight in three and four inch telescopes at low to medium magnifications. The brighter members have a triangular arrangement while the fainter ones supply a circular background to the scene.

Webb recorded this neat cluster as "an elegant group with seventh magnitude pair, preceded by a wider one". The first duo is Struve 485, consisting of 6.1 and 6.2 magnitude suns some 18 seconds apart. Their colors are given as white and bluish, respectively. A number of other apparent double stars can also be seen here.

While no match for the multitude of dazzling clusters in nearby Cassiopeia, this little town of lights has a charm all its own and is well worth seeking out. From its isolated aspect in the desert of Camelopardalis, perhaps it might be dubbed the "Oasis" cluster!

NGC-2403

Our final selection from this month's region takes us out of our own galaxy into the far reaches of intergalactic space to another island universe. This is the spiral system NGC-2403, situated midway along a line from Omicron (σ) in Ursa Major to the wide pair of stars 42 and 43 in Camelopardalis. Sweep for it about one degree northwest of 51 Camelopardalis using a low power eyepiece on the telescope itself.

Although brighter than many of the galaxies he discovered for his famous list, NGC-2403 was missed by Messier and left for Herschel to pick up during his great surveys of the heavens. It is number 44 in his class V — very large nebulae — a category that includes a mixture of both galaxies and diffuse nebulae.

This object is both bright and large as galaxies go — magnitude 8.9 and 17 by 10 minutes in size. Some sources consider it to be even more extensive than this — closer to 22 by 12 minutes. Indeed, this remote star city looms large on a dark transparent night and looks every bit this big.

NGC-2403 is readily seen in three and four inch telescopes at about 45 power, and can even be glimpsed in a good finder. Its appearance in six inch and larger instruments is stunning — a cigar shaped glow floating in the void. The description in the NGC gives it a double exclamation mark (!!) which means "remarkable — very much so". Yet this minor showpiece has apparently been overlooked by just about everyone! A dramatic illustration of the neglect accorded this object is the fact that *none* of the classic observing guides and lists include it! Not only Messier, but Webb, Barns, Olcott and many other great observers of the past never saw it. Even most of today's observers seem unaware of its presence. Are you one of them?

When viewed for the first time, NGC-2403 is sure to surprise you, not only because of its appearance in the eyepiece, but that such a fine object could possibly be missed by ardent stargazers. This only serves to bring home a fact known to all active deep sky observers: The sky is full of unexplored and uncharted wonders. These include objects that have been completely overlooked, neglected or even changed in some manner since the time of the great visual surveys by the Herschels and others.

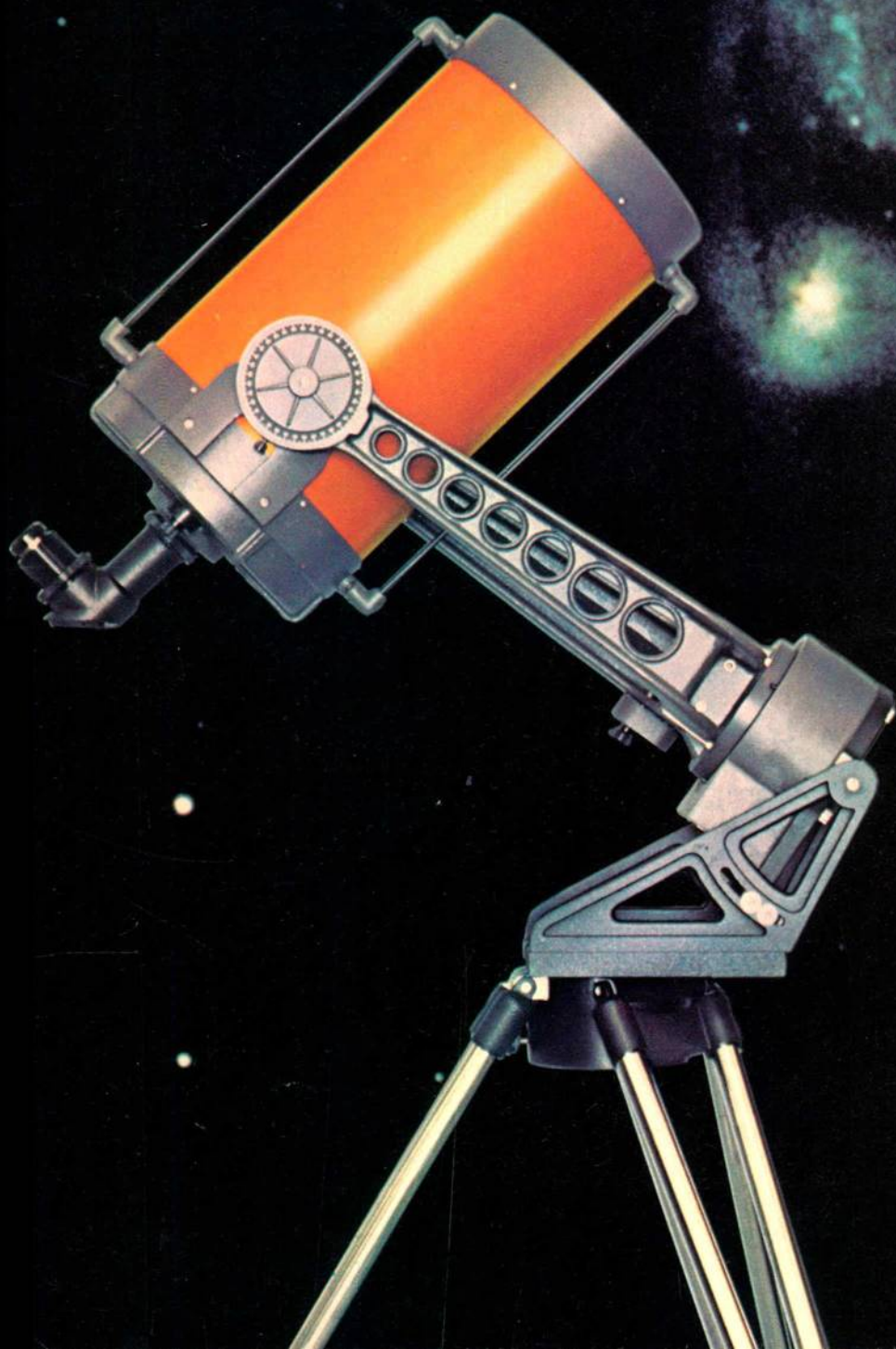
This leaves no question that a new and comprehensive review of the entire heavens is in order, carried out from what might be termed a picturesque or esthetic point of view. The visual impressions of today's observers, using modern instruments and techniques, would be of very great value in "updating" the sky. The work involved would be tremendous — but so, too, would be the rewards!

Perhaps a glimpse of NGC-2403 with your telescope on the next clear night will motivate you to do something about bringing the hidden beauty of the heavens to the attention of the world. Why not give it a look and see what happens?

Our references to the Camelopardalis region as a kind of stellar desert may have conjured up visions of sandy expanses. This in turn brings to mind something written by Henry Wadsworth Longfellow in his poem, *A Psalm of Life*:

"Lives of great men all remind us
We can make our lives sublime,
And, departing, leave behind us
Footprints on the sands of time."

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